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# SURVEY OF ACCIDENTS AT THE AIR SEPARATION PLANTS

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# SURVEY OF ACCIDENTS AT THE AIR SEPARATION PLANTS

ABSTRACT. A large number of accidents which occurred in air separation plants in Japan and elsewhere are analyzed. Claude-type, Linde-type, and Frankel-type separation plants are discussed. Accidents were classified into explosions, bursting accidents and accidents in which humans were injured or killed. Various accident modes are analyzed, and the success of appropriate countermeasures is described. Data on all air separation plants in Japan are given.

## 1. INTRODUCTION

Since air separation plants process a large amount of strong oxidants, such as concentrated oxygen and liquid oxygen at extremely low temperatures and high pressures, the danger of explosions and bursting is constantly present. In our country, numerous accidents have occurred at various locations at air separation plants. /1*

In February 1950, an Air Separation Plant Explosion Accident Countermeasure Committee was formed by the nationwide organizations which are involved with the air separation plants. Explosion accidents and the pertinent information are reported to the committee which was formed for the purpose of conducting scientific investigations. The committee which is assisted by the

*Numbers in the margin indicate pagination in the original foreign text.

High Pressure Gas Group, Inorganic Section, Bureau of Chemistry, Ministry of International Trade and Industry is composed of:

High Pressure Gas Association,

Ammonium Sulfate Industry Rehabilitation Conference (presently, Nippon Ammonium Sulfate Industrial Association),

Lime Nitrogen Association (presently, Lime Nitrogen Industrial Association),

Oxygen Association,

Air Separation Plant Manufacturers.

The committee compiled information pertaining to: the air separation plants; the explosion accidents involving the air separation plants; the analytical liquid oxygen methods; and the investigation of the lubricating oil employed [1].

The final conference by the committee was held on the $14^{th}$, $15^{th}$ and $16^{th}$ of December 1950. At the conference, the Ministry of International Trade and Industry, the Academic Society, and the Industrial Society arrived at a conclusion that such a survey should be continued in the future.

As a result, the following research members which are concerned with the prevention of the air separation plant accidents received a mining industry testing and research subsidy from the Ministry of International Trade and Industry in 1951. They conducted studies on the following three subjects and summarized the data [11] by the end of December 1952.

Research Members: Nippon Rika Industry Co. (Representative)
Tohoku University
Yokohama National University
Showa Electric Co.
Nippon Oil Co.

Subjects: 1. Methods and equipment for the prevention and elimination of harmful substances, and determination of the causes of explosions.

2. Study on the detection, and quantitative analysis of harmful substances in the air separation plant.
3. Decide on the specifications for lubrication oils employed in the air compressor.

Despite the results obtained from such investigations, the real causes of the explosions in air separation plants were not detected.

The Safety Engineering Association was founded in May, 1961, for the purpose of collectively studying the various problems pertaining to preventative techniques against explosion, fire, poisoning, injury, and occupational diseases. Its function, also, is to apply the findings to actual problems with the objective of contributing to a healthy growth of the industry. The association issues a technical journal entitled "Safety Technology", in which there is a serial entitled "Analysis of Hazards", in response to numerous requests by the members. In connection with the above association, it was decided that a committee should be formed to analyze the hazards involved with air separation plants. On July 17, 1962, the Chairman, Katsutaro Shibata, in a letter requested the Light Industry Bureau of the Ministry of International Trade and Industry, Nippon Ammonium Sulfate Association, the Lime Nitrogen Industrial Society, the Oxygen Society, Nippon Steel Association, and the manufacturers of the air separation plants to join and cooperate with the plan. On August 3, 1963, the first Air Separation Plant Hazard Research Committee Conference was held at the Nippon Oxygen Company. The committee chairman and the members were selected as shown in the following table. It was decided that the Nippon Ammonium Sulfate Industrial Association should cooperate by serving as the secretary for the committee.

Subsequently, a subcommittee was formed on April 19, 1964 for the purpose of conducting investigations of every incident, and analyzing the causes. The subcommittee is composed of members as indicated in the following page. The function of the subcommittee is to extract those accidents pertaining to the air separation plant from the accident investigation reports on high pressure gases, which are submitted by the prefectures to the Ministry of International

MEMBERS OF THE COMMITTEE

/2

| | | | |
|---|---|---|---|
| Chairman | 0 | Tetsuzo Kitagawa | Yokohama National University, Professor, Engineering Dept. |
| Member | 0 | Churyo Aida | Nippon Oxygen, Operation Section, Technical Department |
| Member | | Kenichi Iijima | Nippon Iron Steel Association, Investigation Bureau. |
| Member | | Shujiro Ishimura | Sumitomo Chemical Ind., Niihama Production Plan, Asst. Manager, No. 2 Mfg. Dept. |
| Member | 0 | Jiro Ueno | Light Industry Bureau, Ministry of International Trade and Industry, Inorganic Sect. Officer. |
| Member | 0 | Cho Enemi | Teikoku Oxygen, President's Office |
| Member | 0 | Eibu Okada | Nippon Oxygen, No. 3 Design Sect. Design Dept., Tokyo Mfg. Plant |
| Member | 0 | Shigeo Kato | Showa Denko, Kawasaki Plant, Sect. Manager, Fertilizer Mfg. Dept. |
| Member | 0 | Kaname Kawai | Ube Kosan, Manager, Tokyo Adm. Dept |
| Member | | Seizo Sata | Nippon Iron Steel Assn., Labor Bureau |
| Member | | Washiro Sano | Light Ind. Bureau, Ministry of International Trade and Industry, Inorganic Sect., Staff |
| Member | | Seikai Setomoto | Kobe Seiko, Low Temp. Sect., No. 4 Design Dept. |
| Member | 0 | Manabu Teinai | Toyo High Pressure Ind. Head, Safety Group |
| Member | | Kazuo Hashii | Nippon Oxygen, Research Dept. |
| Member | | Saburo Baba | Mitusbishi Kakoki, Manager, No. 2 Technical Dept. |
| Member | | Sachio Hiraike | Hitachi Mfg., Asst. Manager, Plant Dept, Elect. Machinery Dept. |
| Member | | Isao Hoka | Oxygen Assn Executive Director |
| Member | | Yutaka Matsumoto | Nippon Iron Steel Association, Asst. Manager, Investigation Bureau |
| Member | 0 | Shozo Ryuc | Toa Synth. Chem. Ind., Technical Sect., Soda Dept. |
| Member | | Takechi Yoneyama | Sumitomo Chem. Ind., No. 1 Technical Dept., Tokyo Branch |

(CONTINUED)

MEMBERS OF THE COMMITTEE (Continued)

| | | |
|---|---|---|
| Secretary | Sachio Matsuda | Nippon Ammonium Sulfate Assn., Head, Tech. Group |
| Secretary | Mitsuo Kaneko | Nippon Ammonium Sulfate Assn., Tech. Group |

(Note) O - members of subcommittee

(CONCLUDED)

Trade and Industry. Also, by referring to the accidents which occurred in various countries from the foreign literature, surveys were made on the classification, statistics, summary of accidents, and the causes and countermeasures of the accidents pertaining to air separation plants.

As shown in the following tables, the number of committee meetings consisted of five main and thirteen subcommittee meetings. It started in August 1962 and ended in June 1964.

PROGRESS OF THE COMMITTEE MEETINGS

| No. | Date | Location | Attendants | Proceedings |
|---|---|---|---|---|
| Comm. 1 | 8/3/62 | Nippon Oxygen | 17 | (1) Greeting by Chairman Shibata<br>(2) Greeting by Prof. Kitagawa<br>(3) Examination of the Investigation method. |
| Comm. 2 | 8/20/62 | Ammonium Sulfate Assn. | 18 | (1) Translation of the foreign literature on air separation plants.<br>(2) Preparation of survey tables on air separation plan.<br>(3) Investigation of the accidents. |
| Comm. 3 | 12/11/62 | Ammonium Sulfate Assn. | 16 | (1) Survey tables (review) of air separation plants.<br>(2) Explanation on the foreign translation.<br>(3) Analytical methods for accidents. |

/3

(CONTINUED)

PROGRESS OF THE COMMITTEE MEETINGS (Continued)

| No. | Date | Location | Attendants | Proceedings |
|---|---|---|---|---|
| Subcomm. 1 | 4/18/63 | Ammonium Sulfate Assn. | 9 | (1) Prof. Kitagawa explains the progress.<br>(2) Form of the reports.<br>(3) Examination of the classification method of the accidents.<br>(4) Proceedings which are to be submitted to the 4th Comm. meeting. |
| Comm. 4 | 4/20/63 | Ammonium Sulfate Assn. | 15 | (1) Formation of a subcommittee.<br>(2) Survey tables (partly revised) on air separation plant.<br>(3) Classification of the accidents (decide on the classification method).<br>(4) Preparation of the reports.<br>(5) Investigation of the foreign cases (excluding the previous literatures). |
| Subcomm. 2 | 5/23/63 | Ammonium Sulfate Assn. | 9 | (1) Preparation of the schematics.<br>(2) Confirmation of the classification method of the accidents, assignment of the works. |
| Subcomm. 3 | 6/27/63 | Ammonium Sulfate Assn. | 8 | (1) Examination of the schematics.<br>(2) Examination of the classification tables of the accidents which occurred in this country (up to accident type 1.2 b). |
| Subcomm. 4 | 9/19/63 | Ministry of Internat'l Trade and Industry | 8 | (1) Examination of the schematics.<br>(2) Examination of the accidents which occurred in this country (accident type 1 finished). |

(CONTINUED)

PROGRESS OF THE COMMITTEE MEETINGS (Continued)

| No. | Date | Location | Attendants | Proceedings |
|---|---|---|---|---|
| Subcomm. 5 | 10/17/63 | Ministry of Internat'l Trade and Industry | 7 | Examination of the classification tables for the accidents which occurred in this country (accident type 2). |
| Subcomm. 6 | 11/29/63 | Ministry of Internat'l Trade and Industry | | Examination of the classification tables for the accidents which occurred in this country (accident type 3). |
| Subcomm. 7 | 12/20/63 | Ammonium Sulfate Assn. | 7 | Contents of the report and decide on the work assignment. |
| Subcomm. 8 | 1/31/64 | Ammonium Sulfate Assn. | 7 | (1) Partial revision of the clasification method of accidents, and on the statistics of the number of cases.<br>(2) Examination of the classification tables for the accidents which occurred in foreign countries (4 cases).<br>(3) Decide on the assignments of future work. |
| Subcomm. 9 | 2/26/64 | Ammonium Sulfate Assn. | 8 | (1) Treatments of the reports.<br>(2) Examination of the classification tables for the accidents which occurred in the foreign countries (1 case).<br>(3) Arrangement of the completed report (Ch. 2 - Ch. 5).<br>(4) Examination of the photogr attached to the reports.<br>(5) Assignment of future works. |
| Subcomm. 10 | 4/8/64 | Ammonium Sulfate Assn. | 5 | (1) Treatment of the reports.<br>(2) Re-examination of the completed reports (Ch. 2 - Ch. 5).<br>(3) Examination of the causes and countermeasures against accidents. |

(CONTINUED)

PROGRESS OF THE COMMITTEE MEETINGS (Continued)

| No. | Date | Location | Attendants | Proceedings |
|---|---|---|---|---|
| Subcomm. 11 | 5/7/64 | Ammonium Sulfate Assn. | 7 | (1) Re-examination and arrangement of the completed reports (Ch. 2 - Ch. 5).<br>(2) Decide on the assignment of work until the next comm. meeting. |
| Subcomm. 12 | 6/2/64 | Ammonium Sulfate Assn. | 9 | (1) Examination of the introduction.<br>(2) Examination of the schematics.<br>(3) Examination of the countermeasures against explosion accidents.<br>(4) Arrangement of the entire reports. |
| Comm. 5 | 6/11/64 | Ammonium Sulfate Assn. | | (1) Examination of the reports of investigation of the accidents that occurred in air separation plants. |
| Subcomm. 13 | 6/11/64 | Ammonium Sulfate Assn. | | (1) Examination, arrangement, compilation of the entire reports. |

(CONCLUDED)

## 2. SCHEMATICS OF AN AIR SEPARATION PLANT /4

The air separation plants presently installed in our country are shown in the Appendix. Figures 1, 2, and 3 show the standard schematics of the plants involved in the investigation. Figure 4 shows the details of the reboiler. Reference should be made to Section 3.2 for the numbers in the brackets [ ] in the figures.

In the report, the air separation plant refers to everything from the air compressor inlet to the product gas outlet.

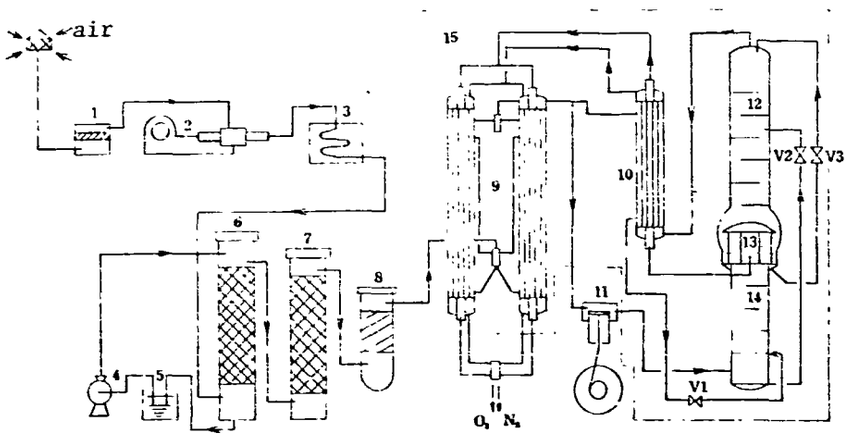


Figure 1. Claude-type air separation plant. 1 - air filter; 2 - compressor; 3 - cooler; 4 - soda pump; 5 - soda liquid tank; 6 - soda column; 7 - dryer; 8 - filter; 9 - heat exchanger (1); 10 - liquefier (heat exchanger) (1); 11 - expander; 12 - liquefaction column upper part (2a); 13 - liquid oxygen tank (2b); 14 - Liquefaction column lower part (2c); 15 - cold box (7); V1 - high pressure expansion valve (6); V2 - liquid air control valve (6); V3 - liquid nitrogen control valve (6).

## 2.1 Claude-type Air Separation Plant

The Claude-type Air Separation Plant is characterized by the cold source which employs a reciprocating type expander. For the production of oxygen and nitrogen, air is compressed to 10 - 40 kg/cm$^2$. Then, after $CO_2$ and water are removed by flowing through the soda column and the drying column, it enters the heat exchanger. Part of this cold air is absorbed by the expander while the other is further chilled by the liquefier, and then expanded by the high pressure expansion valve V1. They subsequently combine and enter from the bottom of the liquefaction column at 5 kg/cm$^2$.

The liquid air and the liquid nitrogen produced are expanded to 0.3 kg/cm$^2$ by the liquid air control valve V2 and the liquid nitrogen control valve V3, respectively, and enter from the top of the liquefaction column. The oxygen and nitrogen evolving from the tip of the liquefaction column are passed

through the heat exchanger and leave the plant at ambient temperature. Although the Highland type empolys the same reciprocating type expander as the Claude type, it differs in that the high pressure air which enters the expander is at ambient temperature.

The low temperature part of the heat exchanger and the liquefaction column are contained in a cold box which is packed with a non-flammable heat insulating material. It is indicated by a broken line in Figures 1 - 3.

## 2.2 Linde Type Air Separation Plant /5

The Linde type is the oldest industrial air separation plant. The early ones used only the expansion valve (Joule-Thomson Effect) as a cold source. Those equipped with a large capacity $NH_3$ freezer are in wide use.

The high pressure air, after $CO_2$ is removed by the soda column, is passed through the external heat exchanger which is composed of two units, and through the $NH_3$ pre-cooler.

Since water condenses on the heat exchanger tubes upon cooling and lowers the heat exchange efficiency, it is periodically switched to heating. The high pressure and low temperature air from the $NH_3$ pre-cooler is further chilled by the internal heat exchanger, and enters the lower part of the liquefaction column via the high pressure expansion valve V1. The evolving oxygen and nitrogen pass through the internal and external heat exchangers, and leave the plant.

## 2.3 Frïnkel Type Air Separation Plant with a High Pressure Cycle

Figure 3 shows the large middle extraction type air separation plant which employs a cold accumulator and an expansion turbine. Since it is capable of simultaneously producing oxygen, nitrogen gases and liquid oxygen, it utilizes a high pressure cycle. The source air enters the cold accumulator

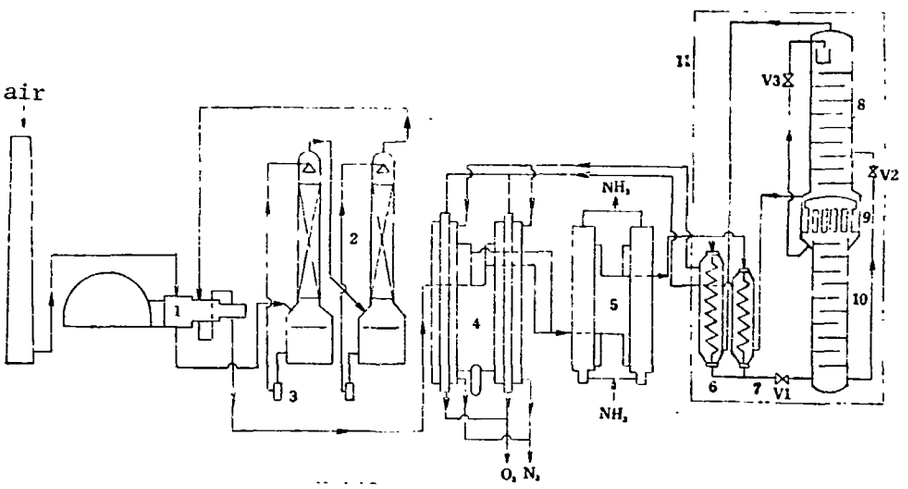


Figure 2. Linde type sir separation plant. 1 - compressor, 2 - soda column, 3 - soda pump, 4 - external heat exchanger (1), 5 - $NH_3$ pre-cooler (heat exchanger) (1), 6 - $N_2$ internal heat exchanger, 7 - $O_2$ internal heat exchanger (1), 8 - liquefaction column upper part (2a), 9 - liquid oxygen tank (2b), 10 - liquefaction column lower part, 11 - cold box (7). V1 - high pressure expansion valve (6), V2. liquid air control valve (6), V3 - liquid nitrogen control valve (6)

after it is compressed to 5.5 atmospheres by the turbo compressor. Since the air extracted from the middle contains $CO_2$, it enters the expansion turbine after $CO_2$ is removed by adsorption. In the high pressure cycle where liquid oxygen is produced, a reciprocating type expander is used. Since the cylinder is an oil lubricating type, an oil filter is provided at the end of the expander. The liquid oxygen at the lower part of the liquefaction column passes through the acetylene absorber and enters the upper part of the liquefaction column. Oxygen is extracted as a liquid from the liquid oxygen tank, vaporized by the sub-condenser, and returns to the cold accumulators. Occasionally a large quantity of liquid oxygen is passed through the sub-condenser and discharged from the liquid oxygen separator for cleaning purposes to prevent any danger of acetylene accumulation.

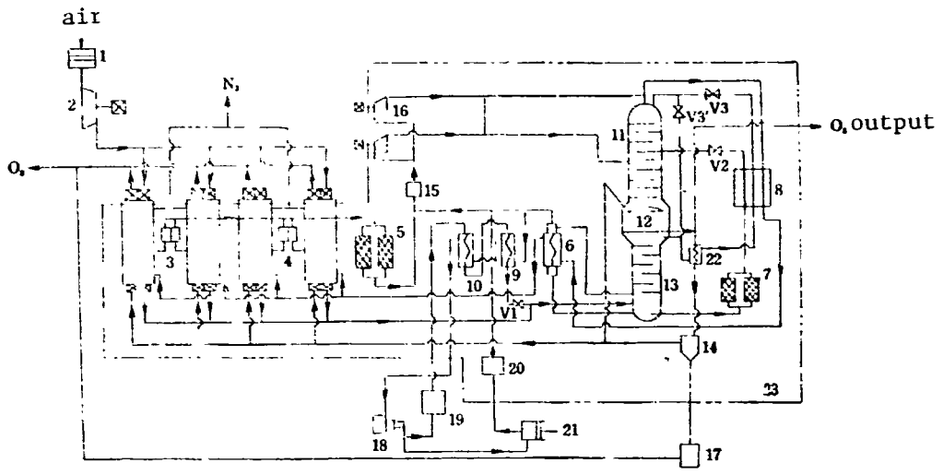


Figure 3. Frankel-type air separation plant with a high frequency cycle. 1 - air filter, 2 - turbo compressor, 3 - cold accumulator (heat exchanger) (1), 4 - cold accumulator (heat exchanger) (1), 5 - $CO_2$ remover, 6 - heat exchanger (1), 7 - acetylene absorber, 8 - super-cooler, 9 - added heat exchanger (cold) (1), 10 - added heat exchanger (hot) (1), 11 - liquefaction column upper part (2a), 12 - reboiler (2b), 13 - liquefaction column lower part (2c), 14 - liquid oxygen separator, 15 - dust remover, 16 - expansion turbine, 17 - vaporizer, 18 - compressor, 19 - oil separator, 20 - oil filter (4), 21 - expander, 22 - sub-condenser (3), 23 - cold box (7). V1 - high pressure expansion valve (6), V2 - liquid oxygen expansion valve (6), V3 - liquid nitrogen expansion valve (6), V3' - liquid nitrogen expansion valve (6). /7

## 2.4 Reboiler

The reboiler is also called condenser, evaporator, vaporizer, main vaporizer, or evaporation condenser. Impurities having higher boiling points than oxygen are concentrated here, thereby creating a cause from accidents. A Linde type is shown in Figure 4 as an example. It has a capacity of producing 7,000 $m^3/h$ $N_2$. Its outer diameter is 950 cm, and has 4,100 straight heat transfer tubes of outer diameter 7.2 cm, inner diameter 6.0 cm, and an average length of $\sim$ 1,000 mm. Evaporation of liquid oxygen takes place on the outside while nitrogen is condensed inside the tube.

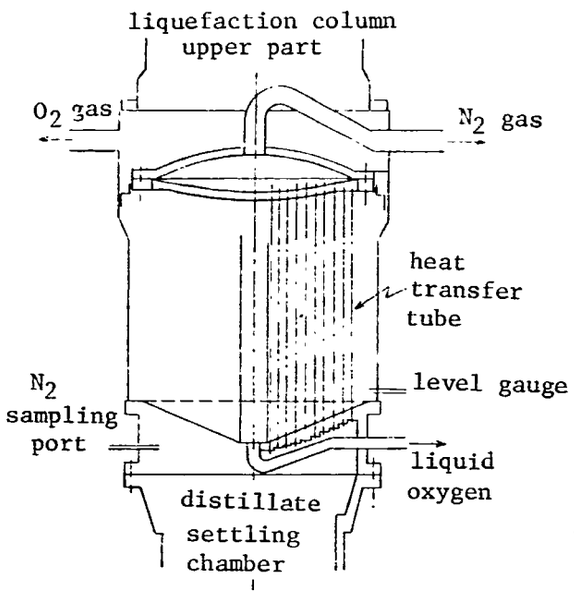


Figure 4. An example of a reboiler (Linde type)

## 3. STATISTICS OF CASUALTIES CONNECTED WITH AN AIR SEPARATION PLANT

The total number of casualties encountered in this country in connection with the air separation plant is 48. They are classified as follows.

### 3.1 Classification by the type of of accident.

Table 4 shows the accidents connected with the air separation plant classified by their types.

TABLE 1. CLASSIFICATION OF ACCIDENTS BY THE TYPE

| No. | Accidents | Number of Accidents |
|---|---|---|
| 1. | Explosion | 37 |
| 2. | Bursting | 6 |
| 3. | Burn | 3 |
| 4. | Frost-bite | 1 |
| 5. | Suffocation | 1 |
| | Total | 48 |

### 3.2 Classification of Accidents by the Location

Table 2 shows the classification of accidents by the location.

TABLE 2. CLASSIFICATION OF ACCIDENTS BY THE LOCATION

| No. | Location | Number of Accidents |
|---|---|---|
| 1. | Heat exchanger | 6 |
| 2. | Liquefaction column | |
| a. | Upper column | 0 |
| b. | Reboiler | 24 |
| c. | Lower column | 4 |
| 3. | Sub-condenser | 2 |
| 4. | Filter | 1 |
| 5. | Pipelines | 4 |
| 6. | Valve | 2 |
| 7. | Inside the cold box | 0 |
| 8. | Outside the cold box | 0 |
| 9. | Pit | 4 |
| 10. | Liquid oxygen reservoir | 1 |
| | Total | 48 |

Note: Pipelines refer to the pipes connecting the various components of the air separation plant.

### 3.3 Classification by Industry

Table 3 shows the classification by industry.

TABLE 3. CLASSIFICATION BY INDUSTRY

| No. | Industry | Number of Accidents |
|---|---|---|
| 1. | Fertilizer | 18 |
| 2. | Chemical | 5 |
| 3. | Oxygen manufacturing | 21 |
| 4. | Iron manufacturing | 2 |
| 5. | Shipbuilding | 2 |
| | Total | 48 |

TABLE 4. YEARLY BREAKDOWN BY THE NUMBER OF ACCIDENTS
(1930 - 1963)

| | Year | 1930 | 36 | 37 | 38 | 39 | 40 | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 49 | 50 | 51 | 52 | 53 | 54 | 55 | 57 | 60 | 61 | 62 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Number | 1 | 1 | 1 | 3 | 2 | 1 | 1 | 4 | 2 | 1 | 1 | 4 | 4 | 4 | 1 | 3 | 3 | 2 | 1 | 4 | 1 | 1 | 1 | 1 | 48 |
| Type of Accident | Explosion | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 4 | 2 | 1 | 1 | 4 | 4 | 2 | 1 | 1 | 2 | | 1 | 3 | 1 | 1 | 1 | | 37 |
| | Bursting | | | | | | | | | | | | | | 1 | | 2 | | 1 | | 1 | | | | 1 | 6 |
| | Burn | | | | 1 | 1 | | | | | | | | | | | | 1 | | | | | | | | 3 |
| | Frostbite | | | | | | | | | | | | | | 1 | | | | | | | | | | | 1 |
| | Suffocation | | | | | | | | | | | | | | | | | | 1 | | | | | | | 1 |
| Location of Accidents | 1 | | | | 1 | | | | | 1 | | | | 1 | | | 2 | | | | 1 | | | | | 6 |
| | 2a | | | | | | | | | | | | | | | | | | | | | | | | | 0 |
| | 2b | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 2 | | 2 | 1 | 1 | 2 | | | 2 | 1 | 1 | | | 24 |
| | 2c | | | | | | | | 1 | | | | | | 1 | | | | | 1 | | | | | 1 | 4 |
| | 3 | | | | | | | | | | | | | 2 | | | | | | | | | | | | 2 |
| | 4 | | | | | | | | | | | | | | | | | | | | | | | 1 | | 1 |
| | 5 | | | | | | | | 1 | | | | 1 | 1 | | | | | 1 | | | | | | | 4 |
| | 6 | | | | | | | | | | | | 1 | | | | | | | | 1 | | | | | 2 |
| | 7 | | | | | | | | | | | | | | | | | | | | | | | | | 0 |
| | 8 | | | | | | | | | | | | | | | | | | | | | | | | | 0 |
| | 9 | | | | | 1 | | | | | | | | | 1 | | | 1 | 1 | | | | | | | 4 |
| | 10 | | | | 1 | | | | | | | | | | | | | | | | | | | | | 1 |
| Industries | Fertilizer | | 1 | | 2 | | | 1 | 1 | 1 | | 1 | 3 | 3 | 1 | | 1 | 1 | | | | 1 | 1 | | | 16 |
| | Chemical | | | | | | | | | | | | | 1 | 1 | 1 | | 1 | | | 1 | | | | | 5 |
| | Oxygen | 1 | | 1 | 1 | 2 | 1 | | 3 | 1 | | | 1 | | 1 | | 2 | | 2 | 1 | 2 | | | 1 | 1 | 21 |
| | Iron Mfg. | | | | | | | | | | | | | | 1 | | | | | | 1 | | | | | 2 |
| | Shipbuilding | | | | | | | | | | 1 | | | | | | | 1 | | | | | | | | 2 |

Note: 1. Refer to Table 2 for the numbers indicated in the Location of Accident column.
2. Although casualties related to the high pressure gas in this country have been recorded since 1918, those pertaining to the air separation plant were not recorded before 1930.

TABLE 5. MONTHLY CLASSIFICATION

| Month | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Explosion | 4 | 2 | 2 | 3 | 1 | 2 | 4 | 5 | | 7 | 3 | 4 | 37 |
| Bursting | 1 | | 1 | | 1 | | | | 1 | | 1 | 1 | 6 |
| Human Accident (Burn, Frostbite, suffocation) | 1 | | | | | | 1 | 1 | | | 1 | 1 | 5 |
| Total | 6 | 2 | 3 | 3 | 2 | 2 | 5 | 6 | 1 | 7 | 5 | 6 | 48 |

TABLE 6. RELATIONS BETWEEN THE TYPE AND THE LOCATION OF THE ACCIDENTS

| Classification | | Location of Accidents | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | | | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| | | | a | b | c | | | | | | | | |
| Type of Accident | Explosion | 3 | | 24 | 2 | 2 | 1 | 3 | 2 | | | | |
| | Bursting | 3 | | | 2 | | | 1 | | | | | |
| | Burns | | | | | | | | | | | 2 | 1 |
| | Frostbite | | | | | | | | | | | 1 | |
| | Suffocation | | | | | | | | | | | 1 | |

Note: Refer to Table 2 for the numbers indicated under the Location of Accidents.

TABLE 7. RELATION BETWEEN THE INDUSTRY AND THE TYPE OF ACCIDENT

| Classification | | Industry | | | | |
|---|---|---|---|---|---|---|
| | | Fertilizer | Chemical | Oxygen | Iron Mfg. | Ship Building |
| Type of Accident | Explosion | 15 | 4 | 14 | 2 | 2 |
| | Bursting | 1 | 1 | 4 | | |
| | Burns | 1 | | 2 | | |
| | Frostbite | 1 | | | | |
| | Suffocation | | | 1 | | |

### 3.4 Yearly Classification

Table 4 shows the yearly classification of the casualties.

### 3.5 Monthly Classification

Table 5 shows the monthly classification of the casualties.

### 3.6 Mutual Relationships

Table 6 shows the relationships between the type of accidents and the location. Table 7 shows the relationships between the type of accident and the industry.

## 4. SUMMARY OF THE CASUALTIES RELATED TO THE AIR SEPARATION PLANTS

In Tables 8, 9 and 10, casualties are divided into explosion accident, bursting accident, and human accident (burn, frostbite, suffocation). They are listed chronologically by the location of the accident.

The accident number in the table is the file number employed by the Ministry of International Trade and Industry. Numbers in the industry, type of accident, and the location of accident columns are the classification numbers employed in Tables 3, 1 and 2, respectively.

### 4.1 Explosion Accidents

TABLE 8. EXPLOSION ACCIDENTS IN THE AIR SEPARATION PLANT

| No. | Accident No. | Date | Location | Industry | Separation Plant | | Accident Type | Position of Accident |
|---|---|---|---|---|---|---|---|---|
| | | | | | Type | Capacity | | |
| 1 | B-1-14 | 14 Aug. 1938 | Ube, Yamaguchi Pref. | 1 | Linde | $N_2$ 2,000 $m^3$/hr | 1 | 1 |
| 2 | B-1-29 | 6 Feb. 1944 | Omuda, Fukuoka Pref. | 1 | Claude | $N_2$ 1,000 $m^3$/hr | 1 | 1 (See Photos 1 and 2) |
| 3 | B-1-48 | 30 Aug. 1948 | Kawasaki Kanagawa Pref. | 1 | Linde | $N_2$ 1,200 $m^3$/hr | 1 | 1 |

TABLE 8. EXPLOSION ACCIDENTS IN THE AIR SEPARATION PLANT

| No. | Summary | Cause |
|---|---|---|
| 1 | Explosion occurred on the oxygen side inside the heat exchanger. Outer wall of the bottom copper plate burst. Copper tubes inside were cut, and part of the steel outer cover of the separation plant was damaged. The slag wool flew out. | Due to the accumulation of acetylene or other hydrocarbons. |
| 2 | December 20, 1943 Total heating.<br>February 6, 1944 Since the nitrogen gas in the separation plant became slightly impure, the oxygen vaporizer valve was fully opened in an attempt to raise the purity. Shortly thereafter, it was restored to normal. Approximately after 2 hours of continuous operation, the lower part of the low temperature heat exchanger (liquefier) exploded.<br>The exploded cylinder of the low temperature heat exchanger (liquifier) (diameter 12, thickness 12, length 5631 mm) made of high carbon steel broke into about 70 pieces similar to porcelain. However, there was no change in the physical properties. Outer tank and part of the nearby pipes were damaged | Liquid oxygen came in contact with the adhering lubricating oil. |
| 3 | August 1, 1948 Operation started.<br>August 30, 1948 Around 12 a.m. liquid oxygen became excessive, and $N_2$ purity dropped to 98%. Due to the malfunction of the liquid oxygen level indicator, indicator was showing low. Immediately, ∿ 120 kg liquid oxygen was blown, and gas was supplied at 2 a.m. At 3:05 a.m., an explosion suddenly occurred accompanied by a dull sound, and white smoke gushed out from the inner heat exchanger case, 500 mm of the outer plate of the bottom of the oxygen inner heat exchanger was damaged. There was no damage to the high pressure air side. The outer plate of the bottom of the nitrogen inner heat exchanger was dented, and the solder became loose. The inner heat exchanger case, where the man-hole is attached, was split, and the cover bulged. There was no damage to the liquefaction column. | Liquid oxygen leaked into the inner heat exchanger and evaporated. Hydrocarbon in the liquid oxygen became concentrated and exploded. (Conjecture) |

TABLE 8. EXPLOSION ACCIDENTS IN THE AIR SEPARATION PLANT (Con't)

| No. | Accident No. | Date | Location | Industry | Separation Plant Type | Separation Plant Capacity | Accident Type | Position of Accident |
|---|---|---|---|---|---|---|---|---|
| 4 | B-1-8 | 24 Oct. 1930 | Tokyo | 3 | | | 1 | 2.b |
| 5 | B-1-10 | 9 March 1936 | Higashi Kamahara, Niigata Pref. | 1 | Claude | Air 3,000 $m^3/hr$ | 1 | 2.b |
| 6 | B-1-12 | 17 Oct. 1937 | Yokohama, Kanagawa Pref. | 3 | Claude | $O_2$ 160 $m^3$ | 1 | 2.b (See Photo 3) |
| 7 | B-1-16 | 7 Nov. 1938 | Ube, Yamaguchi Pref. | 1 | Linde | $N_2$ 2,000 $m^3/hr$ | 1 | 2.b |
| 8 | B-1-8 | 12 Aug. 1939 | Kobe, Hyogo Pref. | 3 | Claude | $O_2$ 200 $m^3$ | 1 | 2.b |
| 9 | B-1-19 | 20 Apr. 1940 | Yokohama | 3 | Claude | Air 800 | 1 | 2.b |

TABLE 8. EXPLOSION ACCIDENTS IN THE AIR SEPARATION PLANT (Con't)

| No. | Summary | Cause |
|---|---|---|
| 4. | The high pressure expansion valve was slightly constricted. When it was opened, the reboiler exploded. | Due to the accumulation of acetylene or other hydrocarbons. |
| 5 | Seven years after installation, on the 21st day after drying (normally, dried every 40 - 45 days). Upper column of the central reboiler exploded, and damaged two units of the heat exchanger. The fragments flew all over the plant. | Same as above |
| 6 | During normal operation.<br>Owing to the acetylene plant located inside the plant, it appears that acetylene was mixed in the source air. | Same as above |
| 7 | The explosion occurred at the bottom of the condenser which damaged part of the fiber cover at the top of the separation plant. | Same as above |
| 8 | Acetylene gas appears to have been sucked in from the acetylene plant in the same area. | Same as above |
| 9 | Occurred at 7:06 a.m. Accident resulted from the accumulation of acetylene or other flammable materials on the bottom of the reboiler during a normal operation. The tube-plate on the bottom of the reboiler was damaged. The outer cylinder of the reboiler swelled and broke the tube-plate into several pieces causing it to peel off from the tube and the outer cylinder. | Same as above |

TABLE 8. EXPLOSION ACCIDENTS IN THE AIR SEPARATION PLANT (Con't)

| No. | Accident No. | Date | Location | Industry | Separation Plant Type | Separation Plant Capacity | Accident Type | Position of Accident |
|---|---|---|---|---|---|---|---|---|
| 10 | B-1-24 | 17 May 1942 | Ube, Yamaguchi Pref. | 1 | Linde | $N_2$ 2,000 $m^3/hr$ | 1 | 2.b |
| 11 | B-1-26 | 9 Aug. 1943 | Sasebo Nagasaki Pref. | 3 | | | 1 | 2.b |
| 12 | B-1-27 | 23 Oct. 1943 | Ube, Yamaguchi Pref. | 1 | Linde | $N_2$ 2,000 $m^3/hr$ | 1 | 2.b |
| 13 | B-1-30 | 21 Feb. 1944 | Yokohama Kanagawa Pref. | 3 | Highland | $O_2$ 120 $m^3/hr$ | 1 | 2.b (See Photos 4 and 5) |
| 14 | B-1-31 | 30 Jan. 1945 | Nagasaki Nagasaki Pref. | 6 | Highland | | 1 | 2.b (See Photos 6 and 7) |

TABLE 8. EXPLOSION ACCIDENTS IN THE AIR SEPARATION PLANT (Con't)

| No. | Summary | Cause |
|---|---|---|
| 10 | The part that liquefies nitrogen by the heat of vaporization of oxygen exploded. There was no operational trouble. | Same as above |
| 11 | At 6:15 a.m. the part corresponding to the reboiler at the bottom of the liquefaction column suddenly exploded. (The plant was very old — the reboilers for the oxygen and air were combined into a single unit). | Acetylene accumulated in the reboiler. In the same area there was a welding acetylene plant. |
| 12 | The part that liquefies nitrogen in the reboiler by the heat of vaporization of oxygen exploded. Did not cause any trouble with the operation. | Due to the accumulation of acetylene or hydrocarbons. |
| 13 | During normal operation.<br>Explosion occurred at the bottom of the reboiler. Due to the pressure all pipes were flattened. Part of the solder on the tube-plate melted and was discolored by the heat. Tube-plate separated from the tube and flew up to the vent windows at the upper part of the building. | Same as above |
| 14 | December 18, 1944. Total heating<br>December 20, 1944 January 7, 1945<br>January 16, 1945 January 26, 1945 } Only upper part heated up.<br>The reboiler exploded causing damage to part of the outer cylinder of the liquefaction column, and bent 13 liquefaction plates. Although a small amount of micro particle oil was found on the back filter of the expander, hardly any oil was adhering to the inside of the heat transfer tubes. A | Same as above |

TABLE 8. EXPLOSION ACCIDENTS IN THE AIR SEPARATION PLANT (Con't)

| No. | Accident No. | Date | Location | Industry | Separation Plant Type | Separation Plant Capacity | Accident Type | Position of Accident |
|---|---|---|---|---|---|---|---|---|
| 15 | B-1-32 | 19 Mar. 1946 | Ube, Yamaguchi Pref. | 1 | | | 1 | 2.b |
| 16 | B-1-37 | 24 Oct. 1947 | Shizuoka Shizuoka Pref. | 3 | Linde | $O_2$ 30 $m^3/hr$ | 1 | 2.b |
| 17 | B-1-42 | 23 Dec. 1947 | Kawasaki, Kanagawa Pref. | 1 | Linde | $N_2$ 1,200 $m^3/hr$ | 1 | 2.b |

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TABLE 8. EXPLOSION ACCIDENTS IN THE AIR SEPARATION PLANT (Con't)

| No. | Summary | Cause |
|---|---|---|
| 14 (cont) | considerable amount of carbon was found on the inside of the damaged separator. | |
| 15 | The separation plant exploded during the switching operation of an old suction column due to the breakdown of the fan. As a result, the copper pipes and the outer cylinder of the reboiler were damaged. In addition, the pipes connecting the top and bottom of the reboiler and the outer cylinder which contains the pipes were damaged, deformed, and the insulator was scattered. | Same as above |
| 16 | During normal operation, about 80 cm of the riveted part at the center of the cold box broke with a large sound, and the asbestos filling was scattered. The copper outer cylinder of the reboiler was split vertically. The upper and lower connections to the liquefaction column were disconnected. | Due to the accumulation of acetylene and hydrocarbons |
| 17 | December 11, 1947 Operation started.<br>December 17, 1947 The stop valve in the liquid oxygen discharge tube exploded and blew off the flange. (B-1-40).<br>December 23, 1947 Reboiler and the liquid oxygen discharge tube exploded. A large crack formed on the outer cylinder of the reboiler and broke all around. The bottom (∿ 30 mm) three rows of copper tubes from the out periphery flattened due to pressure. Among the eight liquid oxygen discharge tubes, three broke within 500 mm from the connection. One broke near the lower blow valve. | Same as above |

TABLE 8. EXPLOSION ACCIDENTS IN THE AIR SEPARATION PLANT (Con't)

| No. | Accident No. | Date | Location | Industry | Separation Plant Type | Separation Plant Capacity | Accident Type | Position of Accident |
|---|---|---|---|---|---|---|---|---|
| 18 | B-1-50 | 20 Jan. 1949 | Yawata, Fukuoka Pref. | 4 | Highland | | 1 | 2.b |
| 19 | B-1-52 | 21 Oct. 1949 | Uozu, Toyama Pref. | 5 | | | 1 | 2.b (See Photo 8) |
| 20 | B-1-55 | 1 Jan. 1950 | Uozu, Toyama Pref. | 2 | | | 1 | 2.b |
| 21 | B-1-60 | 19 June 1951 | Inashiki-gun Ibaragi Pref. | 3 | | | 1 | 2.b |

TABLE 8. EXPLOSION ACCIDENTS IN THE AIR SEPARATION PLANT (Con't)

| No. | Summary | Cause |
|---|---|---|
| 18 | After the start of the maintenance operation, 20 days elapsed before the explosion. On January 20, five days after the heating of the upper part, the reboiler exploded during normal operation.<br>Part of the cold box broke, and the asbestos insulator was scattered.<br>Bottom of all the copper pipes of the reboiler collapsed. Fourteen liquefaction plates of the upper column and one of the bottom column were damaged.<br>Several empty carbide cans were left in the vicinity. | Same as above |
| 19 | Since the purity of the nitrogen gas dropped to 99.6% as a result of the gas analysis conducted at 7 a.m., valves were adjusted to restore the purity. An explosion suddenly occurred when the oxygen gas valve was adjusted. The upper column of the reboiler and the lower column were severely damaged. Part of the low temperature heat exchanger (liquefier) was deformed and broken. One sustained minor injury. | Same as above |
| 20 | During normal operation.<br>Although the details are unknown, it is attributed to the acetylene gas from the carbide plant. | Same as above |
| 21 | After a week of continuous operation, operation was stopped for approximately 25 minutes in order to attend to the compressor. While adjusting the oxygen expansion valve, the solder on the reboiler and at the connection between the low column came off and formed a crack at the lower part of the reboiler. Also, the lower part of the copper pipes in the reboiler collapsed.<br>There was a carbide warehouse near the air intake column. | Same as above |

TABLE 8. EXPLOSION ACCIDENTS IN THE AIR SEPARATION PLANT (Con't)

| No. | Accident No. | Date | Location | Industry | Separation Plant Type | Separation Plant Capacity | Accident Type | Position of Accident |
|---|---|---|---|---|---|---|---|---|
| 22 | B-1-62 | 6 Apr. 1952 | Aioi Hyogo Pref. | 6 | | | 1 | 2.b (See Photo 9) |
| 23 | B-1-65 | 1 Oct. 1952 | Nagoya Aichi Pref. | 3 | Linde | Air 4,500 $m^3$/hr | 1 | 2.b |
| 24 | B-1-80 | 17 July 1955 | Nagoya Aichi Pref. | 3 | Highland | $O_2$ 120 $m^3$/hr | 1 | 2.b |
| 25 | B-1-83 | 1 Oct. 1955 | Nagasaki Nagasaki Pref. | 3 | | | 1 | 2.b |
| 26 | B-1-91 | 4 July 1957 | Ogaki Gifu Pref. | 1 | | | 1 | 2.b |

TABLE 8. EXPLOSION ACCIDENTS IN THE AIR SEPARATION PLANT (Con't)

| No. | Summary | Cause |
|---|---|---|
| 22 | During the operation of the air separation plant, the reboiler suddenly exploded. The plant had not been cleaned in the past 17 months. | Same as above |
| 23 | Since the results of the test run of the separation plant installed seven months before were not satisfactory, the heat exchanger was heated the day before. At midnight of the same day, an explosion occurred at the liquid surface of the reboiler, and deformed and collapsed the copper pipes. | Due to accumulation of acetylene or hydrocarbons. |
| 24 | From 7:30 a.m., liquid air blow was performed, and stopped at 8 a.m. (due to the holiday). Although an abnormal sound was heard from the machine room at about 3 p.m., since there was no discorder with the separation plant inspection from the outside, the operation was started at 8 p.m. However, since it was not operating properly, all parts were inspected in detail which revealed that part of the outer cylinder of the liquefaction column had burst. | Same as above |
| 25 | On September 30, 1955, total heating was performed in order to repair the separation plant, and the cold box and the slag wool was removed. On October 1, 1955, an explosion occurred and burst the upper column, while the pipe from the reboiler to the liquid level indicator was heated after the inside had been cleaned with trichloroethylene. | Explosion was caused by the reaction of oxygen and trichloroethylene |
| 26 | Since the results of the analysis indicated that acetylene exceeded the limit at 8 a.m., the Silicagel filter was heated. When the operation was resumed at 4:40 p.m., an explosion occurred from the reboiler and destroyed the reboiler. | Due to the accumulation of acetylene and oxygen. |

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TABLE 8. EXPLOSION ACCIDENTS IN THE AIR SEPARATION PLANT (Con't)

| No. | Accident No. | Date | Location | Industry | Separation Plant Type | Separation Plant Capacity | Accident Type | Position of Accident |
|---|---|---|---|---|---|---|---|---|
| 27 | B-1-99 | 9 Nov. 1960 | Toyama Toyama Pref. | 1 | Linde | | 1 | 2.b (See Photo 10) |
| 28 | B-1-28 | 13 Dec. 1943 | Shikama-gun Hyogo Pref. | 3 | Highland | $O_2$ 80 $m^3/hr$ | 1 | 2.b |

TABLE 8. EXPLOSION ACCIDENTS IN THE AIR SEPARATION PLANT (Con't)

| No. | Summary | Cause |
|---|---|---|
| 27 | On July 6, 1960, operation was started. During a normal operation, the inner heat exchanger and part of the cold box (600 x 800) were blown off. Most of the small pipes of the reboiler were bent, and five rows from the outside (200 pipes) were split from the end plate and opened like a flower. Small pipes where the explosion took place were smashed. The outer plate of the reboiler was split causing the pipes to break on the outside. The upper column was completely cut off from the reboiler. Although 20 liquefaction plates were damaged, the lower column was intact. Part of the auxiliary pipes were cut or smashed. Nothing aside from the above was damaged at the cold box (see Figure 5). | Since the plant is constructed such that the oxygen reboiler is pre-cooled by passing liquid air directly to the oxygen reboiler from the air reboiler, it appears that impurities accumulated both at the outlet of the precooler pipe which is opened to the upper part of the reboiler, and at the upper part of the oxygen reboiler pipes. |
| 28 | December 7, 1943 Total heating.<br>December 13, 1943 Explosion took place at the lower part of the liquefaction column, and near the inlet of the expanded air. The soldered area between the cylinder and the air reboiler at the lower part of the liquefaction column became detached, and pushed up the lower part of the liquefaction column and the oxygen reboiler by approximately 2 m. The upper part of the liquefaction column was bent and shortened. The welded area at the lower part of the cold box was cut by the explosion. Since the meter panel in front of the air reboiler was destroyed and pushed out, the air reboiler was dragged by the attached pipes and shifted outside the cold box. Twenty-four liquefaction plates at the lower part of the liquefaction column flew out and damaged approximately 70% of the windown and the entrance door of the building. | Since the Highland type uses lubricating oil inside the expander, the oil was not completely removed. The ignition point is unknown. |

TABLE 8. EXPLOSION ACCIDENTS IN THE AIR SEPARATION PLANT (Con't)

| No. | Accident No. | Date | Location | Industry | Separation Plant Type | Separation Plant Capacity | Accident Type | Position of Accident |
|---|---|---|---|---|---|---|---|---|
| 29 | B-1-72 | 19 Jan. 19[illegible] | Otsu Mie Pref. | 3 | Highland | $O_2$ 30 $m^3/hr$ | 1 | 2.c |
| 30 | B-1-46 | 25 July 1948 | Yawata Fukuoka Pref | 2 | Linde Frankel | $O_2$ 2,000 $m^3/hr$ | 1 | 3 |
| 31 | B-1-49 | 31 Aug. 1948 | Higashikama-hara Niigata Pref. | 1 | Claude | Air 3,000 $m^3/hr$ | 1 | 3 (See Photos 11 and 12) |
| 32 | | 13 July 1961 | Kawasaki Kanagawa Pref. | 3 | Liquid Oxygen Type | $O_2$ 1,000 $m^3/hr$ | 1 | |

TABLE 8. EXPLOSION ACCIDENTS IN THE AIR SEPARATION PLANT (Con't)

| No. | Summary | Cause |
|---|---|---|
| 29 | During a normal operation, the air reboiler at the lower part of the liquefaction column exploded, scattered the slag wool (insulator), and broke the window panes of the plant by the blast. Two persons were injured. | Oil appears to have entered from the oil separator. /13 |
| 30 | Due to the malfunction of the stop-valve in the cold accumulator, operation was stopped at 4:05 a.m., repaired, and restarted at 4:30 p.m. Six hours after the oxygen gas was started, part of the copper coil (outer diameter 10 mm, wall thickness 1 mm, length 10 m 500 pieces) inside the sub-condenser suddenly burst. At the same time, the body of the sub-condenser, partition wall, and the cold box burst. | Impurities in the row gas condensed inside the sub-condenser coil. |
| 31 | July 10, 1948. After total heating, the operation had started. No abnormality was detected in the operation even immediately before the accident. August 31, 1948. At 5:25 p.m. the underground sub-condenser exploded.<br>Outer diameter, and the height of the sub-condenser were 580 mm, and 1,000 mm, respectively. Numerous copper tubes inside burst and part of the cold box was damaged. Part of the basement wall was damaged and caused a water leak. There was no damage to the main body of the separation plant. | Acetylene generated from the carbide waste was sucked in. |
| 32 | June 11. Total heating and cleaning<br>July 13. At 4 p.m. the No. 1 heat exchanger was switched from A to B. Although no disorder was detected at switching, five minutes later the oil filter of the expander exploded. The outer tanks of the No. 2 heat exchanger and the liquid air filter were damaged by the fragments. | |

TABLE 8. EXPLOSION ACCIDENTS IN THE AIR SEPARATION PLANT (Con't)

| No. | Accident No. | Date | Location | Industry | Separation Plant Type | Separation Plant Capacity | Accident Type | Position of Accident |
|---|---|---|---|---|---|---|---|---|
| 33 | B-1-25 | 17 Apr. 1943 | Osaka | 3 | Claude | Air 1,300 $m^3$/hr | 1 | 5 |
| 34 | B-1-26 | 7 Oct. 1947 | Kawasaki Kanagawa Pref. | 1 | Linde | $N_2$ 1,200 $m^3$/hr | 1 | 5 |
| 35 | B-1-45 | 22 June 1948 | Kawasaki Kanagawa Pref. | 1 | Linde | $N_2$ 1,200 $m^3$/hr | 1 | 5 |
| 36 | B-1-40 | 17 Dec. 1947 | Kawasaki Kanagawa Pref. | 1 | Linde | $N_2$ 1,200 $m^3$/hr | 1 | 6 |

TABLE 8. EXPLOSION ACCIDENTS IN THE AIR SEPARATION PLANT (Con't)

| No. | Summary | Cause |
|---|---|---|
| 33 | April 4, 1943. Total heating. Since trouble developed in the liquid air control valve for the lower part of the liquefaction column to the upper part, the valve was fully opened when about 1 m of the copper pipes after the valve (outer diameter 40 mm, thickness 1.5 mm) broke into several pieces. The control valve separated from the joint. The small pieces of the copper pipes were discolored to a light black. One of the technicians operating the liquid air control valve was injured. | It appears that the lubricating oil was adhering to the valve and the inner wall of the copper pipe. |
| 34 | July 10, 1947. At 12:25 a.m. during normal operation, an explosion occurred before the valve for the liquid air withdrawal pipe for the argon gas and liquid oxygen was open. The liquid oxygen withdrawal pipe for the argon gas had not been in use. | Due to the evaporation of liquid oxygen while the valve had not been in use, impurities became concentrated. |
| 35 | July 3, 1948. Since there was no accumulation of liquid oxygen 30 hours after the operation was started, the manhole was opened to conduct an investigation. As a result, it was found that there was a fracture in the liquid oxygen blow pipe before the valve. Since there was no abnormality in the previous operation, presumably bursting took place during total heating. | Same as above /14 |
| 36 | During a normal operation, one hour after the liquid oxygen blow-out, the flange of the stop valve (3/4 B) on the unused side burst. There was no other bursting. | Same as above |

TABLE 8. EXPLOSION ACCIDENTS IN THE AIR SEPARATION PLANT (Con't)

| No. | Accident No. | Date | Location | Industry | Separation Plant | | Accident Type | Position of Accident |
|---|---|---|---|---|---|---|---|---|
| | | | | | Type | Capacity | | |
| 37 | B-1-86 | 10 Dec. 1955 | Yawata Fukuoka Pref. | 4 | | | 1 | 6 |

| | Summary | Cause |
|---|---|---|
| 37 | During the manipulation of the liquid oxygen blow out valve of the No. 2 separation plant, the valve burst. Liquid oxygen flowed over the operator who fell on the floor after having been struck in the face by the fragments. | It appears that impurities adhering to the valve exploded by the friction during manipulation. |

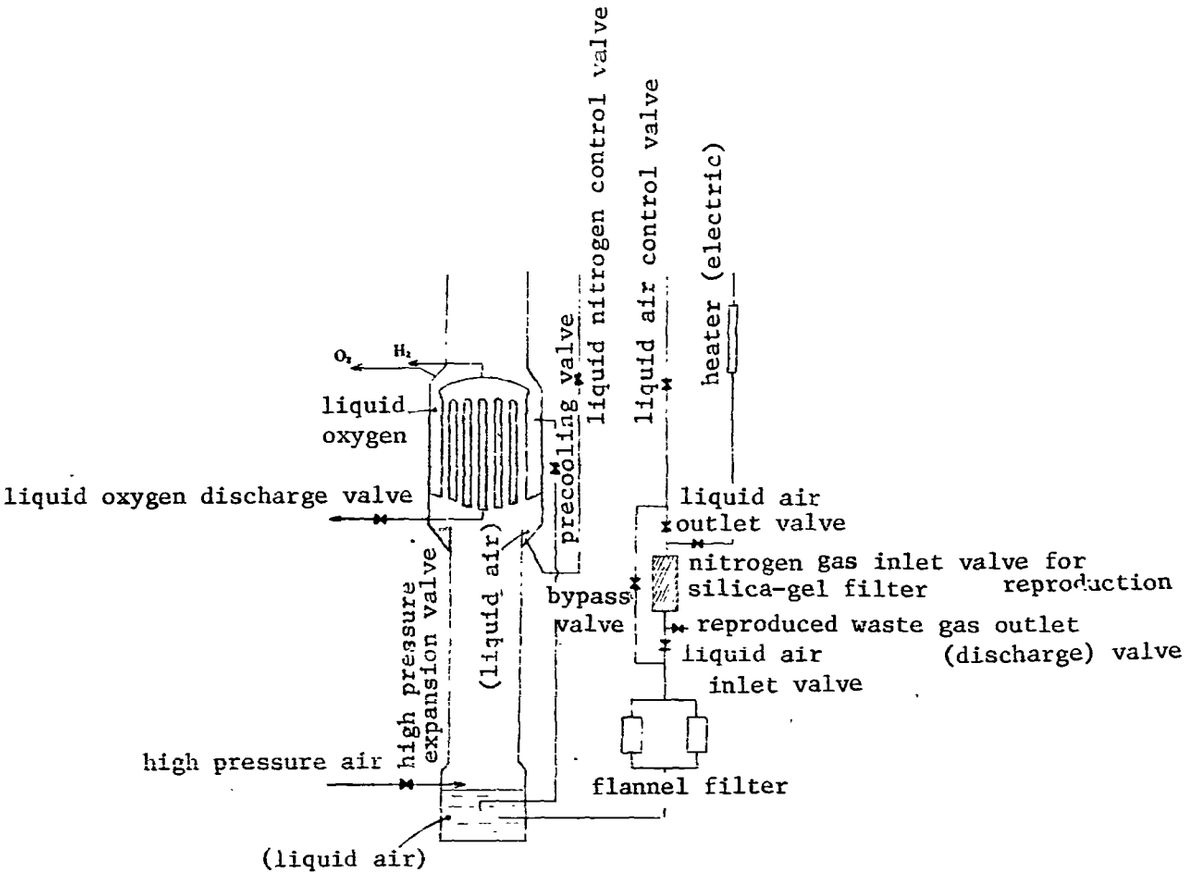


Figure 5. Supplemental figure for accident No. 27, Table 8.

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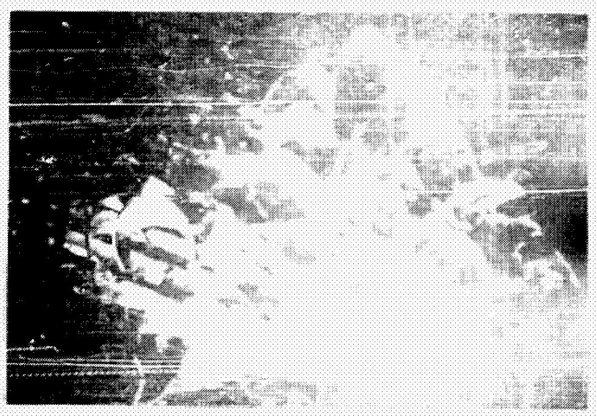
Photograph 1, Table 8, No. 2 Accident No. B-1-29, Occurred on February 6, 1944.

Explosion occurred by the reaction of liquid air and lubricating oil adhering on the outside of the copper pipes of the low temperature heat exchanger (liquefier). Lower part of the copper pipes (just above the board to which the pipes are fastened) was crushed by the external pressure indicating the origin of the explosion.



Photograph 2. The same accident as No. 2, Table 8.

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The cylinder of the low temperature heat exchanger (liquefier) burst „into ∿ 70 fragments like porcelain ware.

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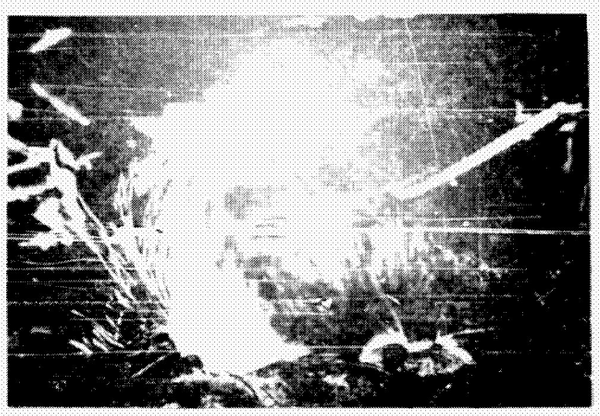

Photograph 3. Accident No. B-1-12, No. 6, Table 8. Occurred on October 17, 1937.

Impurities accumulated on the bottom of the oxygen reboiler and exploded leaving the copper pipes wide open like a flower. Inspection of the lower end of the copper pipes reveals clearly how they were crushed by the external pressure.

Photograph 4. Accident No. B-1-30, No. 13, Table 8. Occurred on February 21, 1944.

The external view of the exploded separation plant. The center part of the outer tank is cut open. The bottom boards of the oxygen reboiler flew up to the vent windows of the building.

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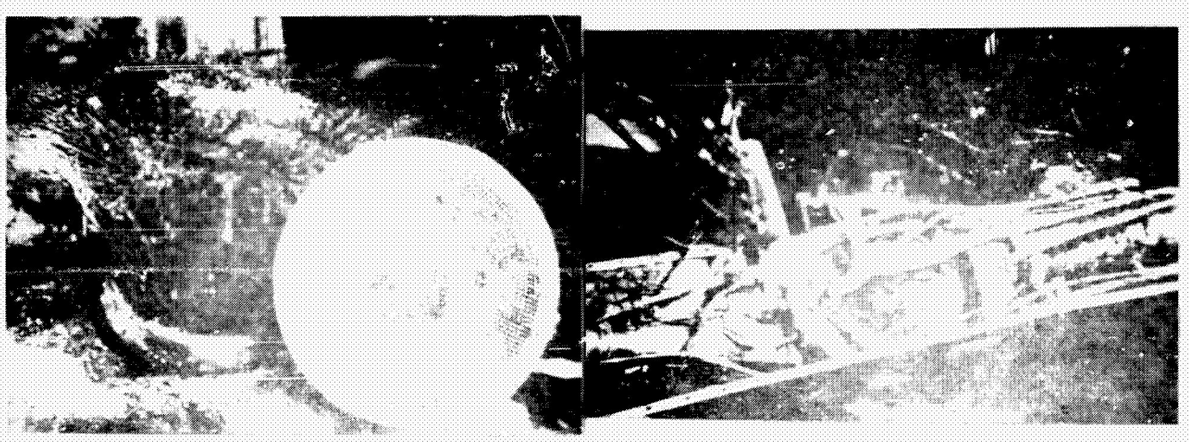

Photograph 5. The same accident as Photograph 4, No. 13, Table 8.

The lower part of the copper pipes of the oxygen reboiler which was the origin of explosion was flattened by the external pressure.

Photograph 6. Accident No. B-1-31, No. 14, Table 8. Occurred on January 30, 1945. /16

The oxygen reboiler exploded, and damaged part of the outer cylinder of the liquefaction column. Thirteen liquefaction plates were bent.

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Photograph 7. The same accident as Photograph 6, No. 14, Table 8.

Lower part of the copper pipes, which was the origin of explosion, was flattened by the external pressure.

Photograph 8. Accident No. B-1-52, No. 19, Table 8. Occurred on October 21, 1949.

Due to the explosion of the oxygen reboiler, the upper part of the liquefaction column, oxygen reboiler, and the lower part of the liquefaction column were severely damaged. The small pipes on the right are the copper pipes of the oxygen reboiler which jumped out during the explosion.

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Photograph 9. Accident No. B-1-62, No. 22, Table 8. Occurred on April 6, 1952.

Explosion of the oxygen reboiler. Inspection of the lower part of the copper pipes reveals that they were crushed by the external pressure indicating the origin of explosion.

Photograph 10. Accident No. B-1-99, No. 27, Table 8. Occurred on November 9, 1960.

Explosion of the oxygen reboiler similarly to Photographs 3 - 9. This is an example where the explosion occurred at the upper part instead of at the bottom. Due to the use of a precooling pipe which is opened at the upper part of the oxygen reboiler, impurities accumulated at the outlet of the precooling pipe (marked A, B in the photograph) and at the upper part of the oxygen reboiler copper pipes. They were the origin of explosion (see Figure 5).

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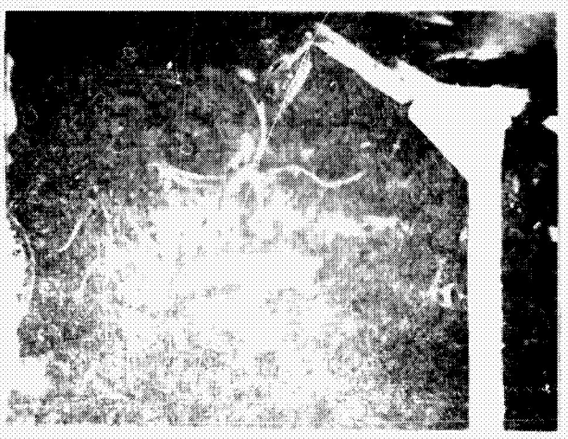

Photograph 11. Accident No. B-1-49, No. 31, Table 8. Occurred on August 31, 1948.

As evident from the number of accidents classified by location, most accidents with the air separation plant occur where impurities are likely to accumulate, that is, a the oxygen reboiler (condenser). Hence, for the purpose of ensuring the safety of the air separation plant, the surface area of the reboiler was increased, and a sub-condenser was installed. An additional heat exchanger (sub-condenser) was installed across the wall from the separation plant, and the oxygen in the reboiler was evaporated through the heat exchanger so that only a small amount of liquid flowed out from the heat exchanger outlet. As a result, impurities in the liquid oxygen were concentrated in a small amount of liquid oxygen. Thus, explosions could be prevented by discarding the small amount of liquid oxygen several times a day. Even when an explosion takes place in the sub-condenser, damage to the air separation plant is prevented by the wall. The photograph shows the explosion of the sub-condenser.

Photograph 12. No. 13, Table 8. The same accident as shown in photograph 11.

As illustrated by photograph 11, the explosion in the sub-condenser did not inflict any damage to the separation plant.

4.2 Bursting Accidents

TABLE 9. BURSTING ACCIDENTS IN THE AIR SEPARATION PLANT

| No. | Accident No. | Date | Location | Industry | Separation Plant Type | Separation Plant Capacity | Accident Type | Position of Accident |
|---|---|---|---|---|---|---|---|---|
| 1 | B-1-58 | 1 Jan. 1951 | Toyama Toyama Pref. | 1 | Linde | $N_2$ 1,000 $m^3/hr$ | 2 | 1 |
| 2 | B-1-61 | 2 Sept. 1951 | Nagoya Aichi Pref. | 3 | Claude | | 2 | 1 |
| 3 | B-1-78 | 11 May 1955 | Naoetsu Niigata Pref. | 2 | Linde | $N_2$ 1,500 $m^3/hr$ | 2 | 1 |

TABLE 9. BURSTING ACCIDENTS IN THE AIR SEPARATION PLANT (Con't)

| No. | Summary | Cause |
|---|---|---|
| 1 | Since the high pressure air coil in the No. 1 ammonia precooler was clogged by the soda solution from the soda column, it was stopped and switched to the No. 2 precooler. Subsequently, at 1:40 a.m. during the heating of the No. 1 precooler, it was demolished. Presumably the soda solution in the high pressure air coil froze and burst the pipe. Subsequently, by the heating, the high pressure air melted the frozen part and gushed out of the burst pipe and demolished the outer cylinder of the precooler. | Operational error |
| 2 | According to the records, at 7:00 p.m. the internal pressure of the liquefier (heat exchanger) was 33 kg/cm$^2$. At 7:40 p.m., the liquefier burst with a dull sound and destroyed three pillars. Although the outer cylinder broke into about 20 pieces, they were obstructed by the asbestos of the cold box and did not scatter.<br>Since the unit was a product made during the war when materials were short, welded steel pipes were substituted for copper pipes in the outer cylinder. Hence, the bursting presumably occurred due to the brittleness at this low temperature. | Inferior material. |
| 3 | No. 1 outer heat exchanger was repaired. Nine minutes after it was started, the outer jacket burst with a loud noise. The fault in the welded part of the outer jacket appears to be the cause. | Inferior workmanship. |

TABLE 9. BURSTING ACCIDENTS IN THE AIR SEPARATION PLANT (Con't)

| No. | Accident No. | Date | Location | Industry | Separation Plant Type | Separation Plant Capacity | Accident Type | Position of Accident |
|---|---|---|---|---|---|---|---|---|
| 4 | B-1-53 | 28 Nov. 1949 | Ube, Yamaguchi Pref. | 2 | Linde | $O_2$ 60 $m^3/hr$ | 2 | 2 c |
| 5 | | 19 Mar. 1962 | Tokuyama Yamaguchi Pref. | 3 | Highland | $O_2$ 30 $m^3/hr$ | 2 | 2 c |
| 6 | B-1-71 | 15 Dec. 1953 | Amagasaki Hyogo Pref. | 3 | Claude | $LO_2$ 600 l/hr | 2 | 5 |

TABLE 9. BURSTING ACCIDENTS IN THE AIR SEPARATION PLANT (Con't)

| No. | Summary | Cause |
|---|---|---|
| 4 | At 12:45 a.m. during the leak test of the high pressure parts up to the liquefaction column of the separation plant, due to the leaky high pressure expansion valve (V1), high pressure (~ 30 kg/cm$^2$) entered the lower part of the liquefaction column causing the pressure to rise and burst the lower part of the liquefaction column. | Faulty V1 valve, and operational error |
| 5 | After the maintenance and inspection of the machines, pressurization (high pressure 200 kg/cm$^2$) was started at 5:05 p.m. At 5:20 p.m., the cooling operation of the separation plant followed. Although everything was normal thereafter, the high pressure expansion valve was closed at 6:40 p.m. since the pressure of the lower part of the liquefaction column rose. However, since the pressure did not decrease, although the air compressor was stopped, the lower cylinder burst with a loud sound shortly before this was done.<br><br>After the accident, investigations revealed that the valve was inoperative because the screw had been stripped by friction. Although the opening of the high pressure blow valve would have prevented the bursting, due to an operational error, emergency stopping of the compressor was attempted causing the delay. | Faulty high pressure expansion valve, and an operational error |
| 6 | Because of errors in the manipulation of the switching valve on the filter for the expanded air, the pipe on the outlet side of the expander was closed, causing the pipe from the expander to the filter to burst. Since the pipe to the safety valve was clogged, the safety valve did not function. Two persons were injured. | Wrong manipulation, and a faulty valve |

## 4.3 Human Accident (Burn, Frost-bite, Suffocation)

TABLE 10. HUMAN ACCIDENT (BURN, FROST-BITE, SUFFOCATION) IN THE AIR SEPARATION PLANT

| No | Accident No. | Date | Location | Industry | Separation Plant Type | Separation Plant Capacity | Accident Type | Position of Accident |
|---|---|---|---|---|---|---|---|---|
| 1 | B-1-17 | 4 Jan. 1939 | Tokyo | 3 | | | 3 | 9 |
| 2 | B-1-67 | 5 Nov. 1952 | NishiKeijogun Niigata Pref. | 1 | Claude | | 3 | 9 |
| 3 | B-1-13 | 13 July 1938 | Tokyo | 3 | | | 3 | 10 |

TABLE 10. HUMAN ACCIDENT (BURN, FROSTBITE , SUFFOCATION) IN THE AIR SEPARATION PLANT (Con't)

| No. | Summary | Cause |
|---|---|---|
| 1 | For the repair of pipes, two workers entered the drain separator underground pit (1.8 m x 2 m H, made of concrete, with a cover) at the entrance of the oxygen holder. At the time, oxygen was flowing out from the disconnected pipe and filling the pit. When the workers attempted to strike a match to light a candle, the clothes ignited in the oxygen stream. One person died. One person suffered burns. | Combusion of clothes in oxygen rich air. |
| 2 | In order to remove one of the five separation units, workers were breaking up the concrete with chisels and hammers inside the pit. At this time, the liquid air which was discharged from the separation plant flowed inside the pit and raised the oxygen content. Sparks from the chisel ignited the worker's clothes. Six persons suffered burns and died. | Same as above. |
| 3 | In order to inspect the inside of the newly installed liquid oxygen tank (brass, thickness 3 mm, diameter 1.8 m, height 2 m), all the liquid oxygen was discharged. The pressure inside the tank was lowered to an atmospheric pressure, and after a day workers opened the manhole and entered the tank. At this time, a match was struck to light a cigarette which ignited the oil-soaked clothes in the oxygen stream. Approximately 20 minutes later the worker was rescued from the pit, but die from burns over the entire body. | Same as above. |

TABLE 10. HUMAN ACCIDENT (BURN, FROST-BITE, SUFFOCATION) IN THE AIR SEPARATION PLANT (Con't)

| | Accident No. | Date | Location | Industry | Separation Plant Type | Separation Plant Capacity | Accident Type | Position of Accident |
|---|---|---|---|---|---|---|---|---|
| | B-1-54 | 10 Dec. 1949 | Nagoya | 1 | Claude | $O_2$ 520 $m^3/hr$ | 4 | 9 |
| 5 | B-1-70 | 8 Aug. 1953 | Kariya Aichi Pref. | 3 | Claude | $O_2$ 520 $m^3/hr$ | 5 | 9 |

TABLE 10. HUMAN ACCIDENT (BURN, FROST-BITE, SUFFOCATION) IN THE AIR SEPARATION PLANT (Con't)

| No. | Summary | Cause |
|---|---|---|
| 4 | Two worke entered the pit (3.25 m x 4 m x 4 m H) where the separation plant is installed in order to inspect the stoppage of the drain-pipe of the heat exchanger and died. | Although the examining doctor attributed death to freezing, the worker presumably died from the leaking cold gas. |
| 5 | Since the purity of the generating oxygen from the separation plant did not improve, it was suspected, as a result of investigation, that a high pressure air was mixed in due to a broken oxygen pipe in the heat exchanger. Hence, the incoming oxygen was stopped while the operation was continued, and the cover at the bottom of the heat exchanger was removed. While striking the blind plug of the broken pipe, two workers became unconscious. Three others who entered to rescue them also became unconscious. All five regained consciousness after the operation was stopped, and treatment was given. | When the bottom cover of the heat exchanger was removed, although oxygen was stopped, nitrogen continued to discharge. Hence, the oxygen concentration decreased, and the workers suffocated. |

## 5. SUMMARY OF ACCIDENTS WITH THE AIR SEPARATION PLANT IN FOREIGN COUNTRIES

TABLE 11. THE ACCIDENTS IN FOREIGN COUNTRIES

| No. | Accident No. | Date | Location | Industry | Separation Plant Type | Separation Plant Capacity | Accident Type | Position of Accident |
|---|---|---|---|---|---|---|---|---|
| 1 | | 11 Jan. 1956 (S.31) | Monsanto Chemical Texas, Texas | 2 | Total Low Pressure | Unknown | 1 | 2.b |
| 2 | | 30 Sept. 1959 (S.34) | DOFASCO Co. Dominion, Ontario, Canada | 4 | Ale Liquid Canada Part. High Press. | 2640 $Nm^3/hr$ | 1 | 2.b |
| 3 | | 20 Apr. 1960 (S.35) | DuPont Bell, W. Virginia, U.S.A. | 2 | Linde Total Low Press. | Unknown | 1 | 2.b |
| 4 | | 21 Apr. 1959 (S.34) | Imperial Chem. Ind. Billingham on Tees, England [6] | 2 | Air Prod. High Press. Oxygen | $O_2$ 240t/d | 1 | 7 |

TABLE 11. THE ACCIDENTS IN FOREIGN COUNTRIES (Con't)

| No. | Summary | Cause |
|---|---|---|
| 1 | After the operation was started in 1952, periodic repairs were performed, and operation was continued for nine months before the accident. A few days before the explosion, operation was normal.<br>The reboiler exploded, and ∿ 70% of the 25,000 tubes were damaged by the external pressure, and the liquefaction plates of the upper liquefaction column were deformed.<br>The center of the explosion appears to be at the bottom of the reboiler. | Explosive impurities appear to have accumulated on the bottom surface of the reboiler tube. |
| 2 | Around 5 p.m., due to the malfunction of the switching valve timer in the cold accumulator, the temperature of the cold accumulator reached a temperature between -150° - -60°C.<br>Thirty minutes later the timer was repaired, and the operation was back to normal at 7:30 p.m. The explosion occurred at 8:10 p.m. Approximately thirty copper pipes inside the reboiler burst and were blown up above the pipe plate. The stainless steel outer cylinder, the side wall of the cold box, and part of the building were destroyed. | Due to the trouble with the switching valve in the cold accumulator, the temperature rose and discharged hydrocarbons from the acetylene filter. This drastically increased the hydrocarbon content in the reboiler and caused the explosion. |
| 3 | It was satisfactorily operated for ten years. Total heating was performed 72 days before the accident. Two years before the accident it was remodeled for the production of high purity $N_2$. During a normal operation, the explosion suddenly occurred and destroyed the main reboiler, the cold box, the driving panel, the compressor and part of the building. Eleven workers inside the building suffered minor injuries, and twelve outside the building sustained burns. | Hydrocarbons accumulated in the main reboiler. |
| 4 | The lubricating oil of the expansion turbine leaked, reacted with the liquid oxygen leaked from the liquid oxygen pipe connection inside the cold box, and exploded. The plant and the building were destroyed. Three persons died. | Although aside from what is reported in the summary, the cause is unknown judging from the |

TABLE 11. THE ACCIDENTS IN FOREIGN COUNTRIES (Con't)

| No. | Accident No. | Date | Location | Industry | Separation Plant Type | Separation Plant Capacity | Accident Type | Position of Accident |
|---|---|---|---|---|---|---|---|---|
| 5 | | 4 Jan. 1960 (S.36) | Knappsack Grissheim Co. Dortmund, W. Germany. W. Germany[7)] | 3 | Linde Frankel | Air 20,000 $m^3$/hr | 1 | 7 Wooden foundation of the air separation plant. |

TABLE 11. THE ACCIDENTS IN FOREIGN COUNTRIES (Con't)

| No. | Summary | Cause |
|---|---|---|
| 4 (cont) | | damage conditions. A considerable amount of the leaked oil from the expansion turbine was probably soaked in the noninflammable insulator in the cold box. It then reacted with the liquid oxygen which leaked from the pipe connection and soaked into the insulator. It presumably was a favorable condition for the explosion. |
| 5 | December 24, 1960. Operation was stopped for the inspection of machineries, and the copper pipe of the oxygen accumulator was welded. At this time, either from the flame used in the welding or from the heat from the molten metal, the wooden foundation of the plant started to smoulder. Nevertheless, since the boards were covered with a galvanized iron sheet, the smouldering was unnoticed, and the slag-wool was placed back in — which caused the smouldering fire to spread.<br>December 30, 1960. Operation was resumed, and a leak from the lower part of the nitrogen cold accumulator was detected.<br>January 3, 1961. The leak of liquid oxygen from the bottom of the oxygen cold accumulator was found by the leak from the cold box.<br>January 4, 1961. The ignition of the gasket (width ∿ 40 cm, hard rubber packing) at the base of the cold box near the nitrogen cold accumulator was discovered. Although the workers in the vicinity started to extinguish the fire, a big explosion occurred when the inspector rushed to the scene. Fifteen persons died, and most of the air separation plant, and the building were destroyed. | Since liquid oxygen was soaked in the wooden foundation of the air separation plant, the spark from the welding caused the explosion. |

Photograph 13. No. 1, Table 11.
Occurred on January 11, 1956.

The photograph of the explosion of the oxygen reboiler at Monsanto Chemical. The explosion pressure is concentrated just above the bottom connection of the reboiler copper pipes. The deformation of the bottom plate is, also, considerable. As a result of the investigation, presumably the cause of the explosion was due to the formation of a eutectic of acetylene and nitrous oxide.

Photograph 14. No. 1, Table 11.
The same accident as photograph 13.

It indicates that the damage to the reboilers copper pipes was most severe near the bundle of pipes.

# 6. THE CAUSE OF ACCIDENTS IN THE AIR SEPARATION PLANT AND THE COUNTERMEASURES

## 6.1 The Causes of the Explosion Accidents /22

Among the 37 explosion accidents investigated, 24 cases are with the reboiler and two are with the sub-condenser. All 26 cases were caused by the enrichment of hydrocarbons, especially acetylene in liquid oxygen.

The three cases with the pipes in the heat exchanger (Table 8, No. 2, No. 28, No. 29), and the two with the valve (Table 8, No. 36, No. 37) were caused by the seepage of the lubricating oil.

An odd example is the explosion of the reboiler caused by the incomplete removal of trichloroethylene used in cleaning (Table 8, No. 25). Therefore, the fuel in the explosion accident is the hydrocarbons in the source air, or the hydrocarbons or the lubricating oil droplets which mix during the liquefaction of air.

### 6.1.1 Contamination of the Source Air

Exhaust gases discharged from the carbide furnace, the carbide reservoir, the acetylene solution plant, the steel and iron furnaces, the coke furnace, and the oil refineries near the air separation plant contain hydrocarbons and other impurities. The properties of these impurities are shown in Table 12.

These impurities contained in the source air gradually accumulate without being evaporated in the liquefaction column. According to the I.C.I. investigation, air at a 12 m level contains 0.1 - 4 p.p.m hydrocarbons, and approximately a half of this at 16 m above ground level. Almost all the hydrocarbons were found in trace amounts [6]. Many hydrocarbons are found in the atmosphere of Tokyo by gas chromatography [13]. Although

TABLE 12. PROPERTIES OF SOME OF THE AIR POLLUTANTS

| Nomenclature | Formula | Boiling Pt. (°C) | Freezing Pt. (°C) | Nomenclature | Formula | Boiling Pt. (°C) | Freezing Pt. (°C) |
|---|---|---|---|---|---|---|---|
| Carbon monoxide | | | | Isobutane | | | |
| Methane | | | | Isobutylene | | | |
| Nitric Oxide | | | | 1.3-Butadiene | | | |
| Ozone | | | | n-Butane | | | |
| Ethylene | | | | Ethylene Oxide | | | |
| Ethane | | | | Acetoaldehyde | | | |
| Nitrous Oxide | | | (sub- | Nitrogen dioxide | | | |
| Acetylene | | | lima- | n-Pentane | | | |
| Hydrogen Sulfide | | | tion) | Acetone | | | |
| Thiocarbonyl | | | | Methanol | | | |
| Propylene | | | | Hexane | | | |
| Propane | | | | Benzene | | | |
| Formaldehyde | | | | n-Decane | | | |

*Sublimation

TABLE 13. SOLUBILITIES OF VARIOUS SUBSTANCES IN LIQUID OXYGEN AT -196° C

| Substance | Solubility | Substance | Solubility |
|---|---|---|---|
| Methane | 740,000 | Acetone | 1.5 |
| Ethane | 92,000 | Methanol | 12 |
| Propane | 45,000 | Ethanol | 15 |
| n-Butane | 150 | Acetoaldehyde | 0.4 |
| n-Pentane | 20 | Benzene | 4 |
| n-Hexane | 2 | Nitrous Oxide | 50 |
| n-Decane | 0.6 | Hydrogen Sulfide | 70* |
| Acetylene | 1.7 | Thiocarbonyl | 28* |
| Etylene | 1,800 | Nitrogen tetroxide | 15* |
| Propylene | 2,500 | 1.3-Butadiene | 20* |

*at -183° C

the accumulation of any hydrocarbon is dangerous, acetylene is being watched most closely because of its solubility. The allowable amount of hydrocarbon in liquid oxygen can be estimated by its explosion limit and solubility. Table 13 lists the solubilities of various substances in liquid oxygen at -196° C. Tables 14 and 15 show the combustion limits of various substances. These data (Tables 12, 13, 14, 15) were released by Air Products [10]. When the lower limit of combustion is lower than the solubility, the former is the danger limit, and vice versa.

Actually it is difficult to conceive that a gas with a high solubility /23
should be concentrated to its limit. Hence, a highly soluble gas such as methane is unlikely to cause explosions. Along with acetylene, butadiene is being observed, although there are no data which link it to any accident.

6.1.2 Contamination by the lubricating oil

In the reciprocating type compressor, the causes for the emission of gaseous hydrocarbons conceivably are:

(a) Light hydrocarbons are dissolved in the lubricating oil;

(b) The contact with a high temperature cylinder wall causes a decomposition. The result of investigation [6] by I.C.I., however, precluded such theories.

Therefore, as long as the quality of the lubricating oil is adequate, it is unconceivable that the oil can enter the separation plant in a gaseous form. Either the vapor generated during the compression process condenses at the cooler and enters with the air as a mist, or the mist broken up at the discharge outlet is carried over. According to the experiment carried out by I.C.I., evaporation during the compression process is negligible. Furthermore, oil droplets are removed at the cooler and the dryer (high and medium pressure separation plant). When the cold accumulator is

TABLE 14. EXPLOSION LIMITS OF VAPORS

| Compound | Formula | Lower Limit mole % | Lower Limit Per Carbon Atom mole % | Heat of Combustion kcal/mole | Energy Released at the Lower Limit kcal/g mole compound |
|---|---|---|---|---|---|
| Methane | $CH_4$ | 5.00 | 5.00 | 213 | 10.16 |
| Ethane | $C_2H_6$ | 3.00 | 6.00 | 373 | 11.2 |
| Propane | $C_3H_8$ | 2.12 | 6.36 | 531 | 11.3 |
| Butane | $C_4H_{10}$ | 1.86 | 7.44 | 688 | 12.8 |
| Pentane | $C_5H_{12}$ | 1.40 | 7.0 | 845 | 11.8 |
| Hexane | $C_6H_{14}$ | 1.18 | 7.08 | 1002 | 11.8 |
| Nonane | $C_9H_{20}$ | 0.83 | 7.47 | 1473 | 12.2 |
| Decane | $C_{10}H_{22}$ | 0.77 | 7.7 | 1630 | 12.6 |
| Ethylene | $C_2H_4$ | 2.75 | 5.5 | 337 | 9.2 |
| Propylene | $C_3H_6$ | 2.0 | 6.0 | 492 | 9.8 |
| Butene-1 | $C_4H_8$ | 1.65 | 6.6 | 650 | 10.4 |
| Acetylene | $C_2H_2$ | 2.50 | 5.0 | 311 | 7.6 |
| Toluene | $C_7H_8$ | 1.27 | 8.9 | 944 | 12.0 |
| Benzene | $C_6H_6$ | 1.4 | 8.4 | 789 | 11.0 |

employed, (low pressure type), they can be removed completely. Nonetheless, the occurrence of such accidents by the lubricating oil is presumably due to the compounding of unfavorable conditions, such as: the lack of cooling water; air is not purified when heated or when excessive oil is fed in; the air velocity becomes excessive due to a low air pressure.

Since the contamination of the various parts of the separation plant by the lubricating oil is a problem, a periodic clean-up is performed with a solvent.

There is a case where an accident occurred as a secondary accident by the permeation of lubricating oil into the insulators (No. 4, Table 11).

6.1.3 Other Inflammable Materials

TABLE 15. EXPLOSION AND DETONATION LIMITS - GAS PHASE

| Compound | Lower Limit (mole %) | | Upper Limit (mole %) | |
|---|---|---|---|---|
| | Explosion Limit | Detonation Limit | Detonation Limit | Explosion Limit |
| $H_2 - O_2$ | 4.65 | 15 | 90 | 94 |
| $H_2$ - Air | 4.0 | 18.3 | 59 | 74 |
| CO - $O_2$ (wet) | 15.5 | 38 | 90 | 93.9 |
| CO - Air | 12.5 | | | 74.2 |
| $CH_4 - O_2$ | 5.4 | | | 59.2 |
| $CH_4$ - Air | 5.0 | | | 15.0 |
| $C_2H_2$ - Air | 2.5 | 4.2 | 50 | 80 |
| $C_4H_{10}O$ (Ether) - $O_2$ | 2.1 | 2.6 | >40 | 82 |
| $C_4H_{10}O$ - Air | 1.85 | 2.8 | 4.5 | 36.5 |
| $C_2H_6 - O_2$ | 4.10 | | | 50.5 |
| $C_2H_6$ - Air | 3.0 | | | 12.5 |

An accident occurred at Grissheim Co., in Dortmund, where the lumber used in the foundation acted as a fuel (No. 5, Table 11).

6.1.4 Ignition Source

Although numerous data can be furnished regarding the fuels which cause explosions, relatively little is known as to how the fuel is ignited.

According to the report by Air Products, the ozonide of acetylene presumably is the source of ignition. In the experiment, explosions occurred by passing ozone through liquid oxygen on which solid $C_2H_2$ was floating. $C_2H_4$, however, did not explode by the same mechanism — it exploded by the use of a fuse [10]. Their opinion on the oxides of nitrogen, NO, $NO_2$, $N_2O_4$ is negative. They also negate the possibility of an explosion of $N_2O$ at low temperatures.

On the other hand, Monsanto Chemical reports in detail the experiment /24
in which the eutectic of $N_2O$ - $C_2H_2$ (or the mixed solids) exploded by the addition of ozone [6]. Rotzler of Monsanto Chemical reports that $N_2O$ does not greatly contribute to promoting explosions [3]. The report by I.C.I., also, does not regard the oxides of nitrogen important although the situation is different in the purification of $NH_3$ gas.

A method for the quantitative determination of $NO_2$ in liquid oxygen is reported by Kobayashi and Kitagawa [12].

Karwat of Linde and Kerry of L' Air Liquide regard ozone as a prime suspect.

At any rate, the mechanism for the initiation of the explosion cannot be fully explained at the present stage.

## 6.2 Countermeasures Against Explosions

As stated in 6.1, except for 1 (No. 27, Table 8) among a total of 26 accidents of which 24 are related to the reboiler and two to the sub-condenser, 25 occurred in plants which are not equipped with the acetylene filter (gel absorbing column) (it is worse when a welding acetylene plant is located in the same plant area). Hence, in 1950, the Ministry of International Trade and Industry and the Ammonium Sulfate Association formed the Air Separation Plant Explosion Prevention Committee and discussed countermeasures. As a result, in order to prevent the accumulation of acetylene in the reboiler which is the main cause of the explosion — following the example adopted in Germany — it was proposed that a warning limit and a stop limit be established by analyzing acetylene in the silica-gel absorber as well as liquid oxygen. The proposal was incorporated in the new ordinance, and was immediately enforced at the plants. As a result, accidents in the air separation plant were reduced considerably. An accident occurred in this

country (previously described), and two in foreign countries were picked as the objects of this investigation — which will be discussed later.

Accidents caused by the lubricating oil can be prevented by installing filtering equipment in the compressor and the path.

6.2.1 Source Air

Although the degree of contamination of the source air depends on whether there are plants in the vicinity which are generating contaminants, and also the wind direction and the altitude, generally the higher the altitude, the purer the air as indicated in 6.1.1.

Taking the above conditions into consideration, the air intake port should be placed at least at two different locations so that it can be switched depending on the wind direction and the surrounding conditions. Measurements of the amount of contaminants at various conditions, therefore, are necessary beforehand. According to Kerry, the upper limits of the contaminants in the air are as follow:

| | |
|---|---|
| Acetylene | < 1 ppm |
| $NO + NO_2$ | < 1 ppm |
| Ozone | < 0.1 ppm |
| $CO_2$ | < 5 ppm |
| Oil vapor | 0 |

Normally, the acetylene content in the atmosphere is 0.001 ppm, $\sim$ 1 ppm in the industrial area, and can be as high as 15 - 30 ppm in the petroleum chemical plant area.

Although it is necessary to remove the hydrocarbons in the air by oxidation using a catalytic filter in case of a very contaminated air, it

has not been carried out in this country. I.C.I. is employing the M.S.A. catalytic filter at the outlet of the compressor; $\sim$ 6 kg/cm$^2$ abs air is processed at 175° - 300° C [6].

Normally, when the acetylene and the total hydrocarbon content in the liquid oxygen in the reboiler reach the warning limits, either the switching time of the acetylene absorber is shortened, or the air intake port is switched. Also, a countermeasure is set up to bring about a change in the degree of contamination in the vicinity (see 6.2.3 for the details).

### 6.2.2 Infiltration of Contaminants

Most of the solid particles in the source air are removed by filtration. Subsequently, the water soluble compounds, such as ammonia, acetone, and alcohol and those which condense at the cooling water temperature are removed with condensed water at the cooler in the compressor.

In the equipment which employs sodium hydroxide to remove carbon dioxide, all the acidic compounds, such as $H_2S$ and HCN, and most of $NO_2$ are removed.

These which have boiling points in the range 30° - 170° C are theoretically condensed inside the heat exchanger and accumulate until the next heating. These compounds are listed in Table 12.

Nevertheless, these condensates do not necessarily all adhere to the tube wall inside the heat exchanger. There is a possibility that some of them may be carried over to the next step by the air stream or by floating on the liquid.

In the reversible heat exchanger, that is, one which employs a cold accumulator, the above substances are condensed on the surface of the cold

accumulating substance and removed from the air stream. They are subsequently vaporized by the warm gas in the next process and expelled from the plant.

Most of the light hydrocarbons, up to butane and butylene, and NO, $N_2O$, CO, $O_3$, and $H_2$ infiltrate up to the liquefaction column. /25

Among these, $H_2$ escapes with $N_2$ from the top of the column. Part of the CO enters into the liquid phase, but eventually is expelled.

6.2.3 Removal of Contaminants in Liquid

As indicated above, substances which enter into the liquefaction column and accumulate in the reboiler are introduced into the upper column from the bottom of the lower column accompanied by liquid air. Therefore, an acetylene filter (gel absorber) is installed in the pipe which carries liquid to the upper column to remove impurities by absorption.

Two of these filters are installed — one is regenerated by dry nitrogen while the other is being used. It is designed so that they should be switched every 3 - 7 days. It is normally equipped with a pre-filter to prevent contamination of the gel. As long as the source air is in a normal condition, the method can conceivably eliminate explosions completely. This type of accident had not been recorded in our country as a result of establishing the warning limit and installing the absorber. There is only one exception: a liquid transmission pipe was installed for precooling in the reboiler which bypassed the filter from the lower column, and opened to the reboiler, causing the accumulation of acetylene.

A complete control, however, is difficult from the practical standpoint. Problems remain in the future in the prevention of acetylene accumulation, particularly in the analytical technique, and the time delay in discovering

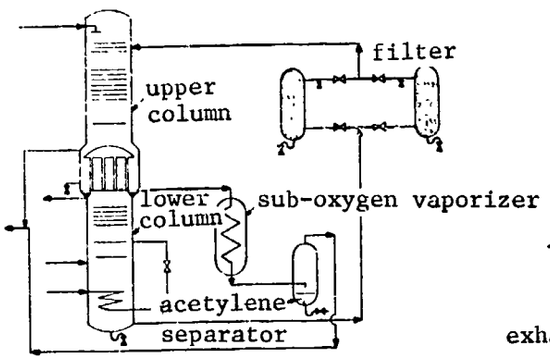


Figure 6. Standard air separation plant equipped with a sub-oxygen vaporizer

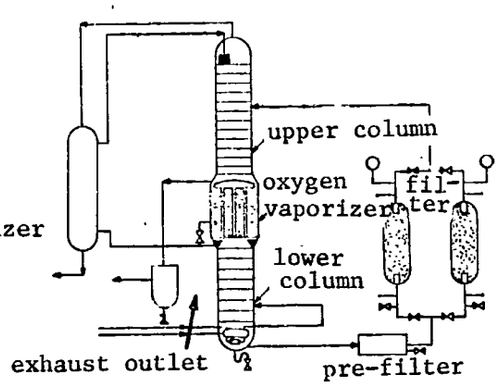


Figure 7. Standard air separation plant without a sub-oxygen vaporizer

the alarm condition. Also, an effective method to remove the accumulated impurities which infiltrated into the reboiler is to remove a constant amount of liquid from the top and bottom. The purpose for installing the sub-condenser (Figure 6) is to confine the danger to a small area in order to minimize the damage.

6.2.4 Various Types and Contaminants

Figure 7 is a schematic diagram of a standard air separation plant in the U.S. The source air is cooled by the product gas at the final stage of the heat exchanger at a pressure of 15 - 25 $kg/cm^2$, and is supplied to the lower part of the liquefaction column.

The operating pressure of the lower column is 4 - 5 $kg/cm^2$. The operating pressure of the upper column, however, is slightly higher than the atmospheric pressure. The liquid in the lower liquid air reboiler contains the impurities which passed through the heat exchanger.

This liquid passes through the acetylene absorber and is supplied to

the upper part of the liquefaction column as a source liquid. When it descends passing through the numerous liquefaction plates, the low boiling component, i.e. the nitrogen evaporates, and separates. Therefore, those impurities which have higher boiling points than oxygen descend through the column with the liquid as solid particles or in liquid form, and enter the reboiler. In the reboiler. oxygen vaporizes by the heat of vaporization of nitrogen in the lower column. In this process, those compounds which have higher boiling point than oxygen do not vaporize but accumulate. Hence, the accumulation of impurities is largest in this type.

In contrast, in the liquid oxygen removal type separation plant, impurities do not accumulate in the reboiler, since liquid oxygen is removed from the plant as a liquid.

For the production of high pressure oxygen gas which has been used recently in chemical industries and steel manufacturing, oxygen is taken out from the column in a liquid state which is then pressurized by the liquid oxygen pump and vaporized in the heat exchanger at a high temperature. Therefore, as far as the impurities are concerned they are the same as the liquid oxygen set up. /26

Since a turbo compressor is used of the total low pressure type, there is no concern about the mixing of the lubricating oil. Also, as indicated in 6.2.2, impurities in the source air are mostly removed by condensation in the cold accumulator. Aside from the main air circuit, in cases where the extracted vapor from the middle (in order to maintain the thermal equilibrium of the cold accumulator) is transported to the upper part of the liquefaction column via the expansion turbine, a carbon dioxide remover is effective as a filter in the circuit.

From the standpoint of safety with regard to vaporizers, Kerry elucidates a type in which the paths of liquid and vapor are reversed;

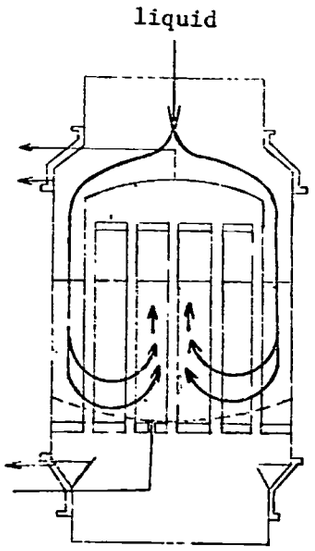


Figure 8. Convection of liquid

liquid circulates from the low pressure column to the high pressure column. Since it is not considered important, a detailed discussion is omitted.

In regard to convection of liquid oxygen in the reboiler, since the liquid flows down to the reboiler from the periphery of the dome at the top of the lower column, the liquid in the periphery of the reboiler has a downward flow, while that in the center has an upward flow. As a result, a stationary region is created at the periphery in the lower part where precipitates are accumulated (see photograph 14, Figure 8). It can be remedied by either providing an angle or a curve at the periphery.

6.2.5 General Control

(1) Air compressor

In the reciprocating type air compressor, it was indicated in 6.1.2 that there is a possibility of lubricating oil entering into the system in some form.

For its prevention, firstly, it is necessary to fix the quality and the quantity of the oil constant. The outlet temperature should be less than 150° C in order to prevent evaporation or thermal decomposition. If it is cooled sufficiently at the final cooler of the middle section, oil vapor should condense.

If a gel dryer is employed, oil vapor can be completely eliminated by keeping the inlet temperature below 5° C.

(2) Dryer

Recently, it has become common practice to use a gel absorption type dryer at the final purification stage of the source air. It is not only more economical than the dryer which uses lumps of sodium hydroxide, but it is much superior from the safety standpoint, since water, oil vapor, and other condensable substances are absorbed by the dryer.

Two gel dryers are installed in parallel, and used alternately; while one is being used, the other is regenerated by air or nitrogen. The instructions by the manufacturer should be followed for the switching time, the purity of the gas used in regeneration, the regeneration time, and the usable length of the gel.

(3) Expander

Since lubricating oil is used in the high pressure air expander for the liquid oxygen, collection type air separation plant, an oil filter is installed. Filters are selected by considering the structure, the material, and the pressure loss. Recently, a superior type — a cylindrical shape made of sintered metal or carborundum, is being manufactured. The instructions of the manufacturer must be followed in regard to the lift time and the oiling rate in order to set an operating standard. Also, a safety valve must be installed at the outlet side of the expander in case of a pressure rise due to the failure of the filter.

(4) Analyses of hydrocarbons and acetylene. Control of acetylene filter.

Although the capacity and the switching time of the acetylene filter

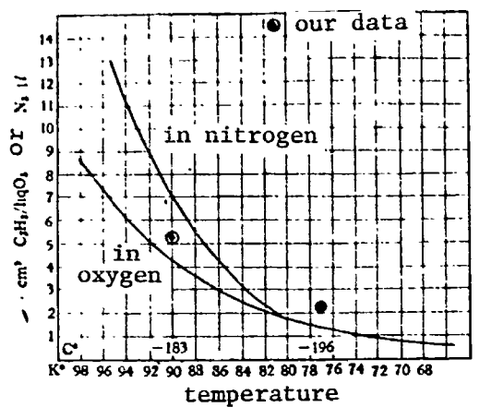


Figure 9. Solubility of acetylene in liquid oxygen and liquid nitrogen.

are set by the manufacturer based on the average purity of the source air, the amount of pollutants fluctuates considerably with time depending on the wind direction, and the operating conditions of the nearby plants. Hence, the switching time, the life time of the ged, and the frequency of analysis of total hydrocarbon and acetylene concentrations must be set individually depending on the environment of the plant, the type, and the capacity.

As a rule, the total hydrocarbon /27 content in liquid oxygen must be kept below the combustion limit, whereas acetylene should be kept below the solubility limit.

Since hydrocarbons excluding acetylene have high solubilities in liquid oxygen, the combustion limit is taken from Table 14. Five mol % (converting to the equivalence of methane) is used as the minimum amount. Hence, 500 ppm ($100^{th}$ of 5 mol %) is taken as the concentration limit for safe operation. As shown in Table 13, the solubility of acetylene is 1.7 ppm according to McKinley, and 5 ppm (5cc/l liquid oxygen) according to Kerry (see Figure 9). The safe allowable amount, however, is taken as 0.5 - 1 ppm. When the result of the analysis is higher than such numbers, the operation must be stopped, and the liquid must be discharged.

In order to prevent the sudden occurrence of this stage, a warning stage must be set at a lower concentration. The frequency of analysis must be increased at this stage, and the concentration of contaminants must be reduced by switching the air intake port depending on the wind direction. Also in this case, it is necessary that the liquid level of the vaporizer

be higher than standard, and most of the pipes be immersed in the liquid. When the liquid level tends to decrease, the temperature of the warm end of the heat exchanger must be examined to ensure that there is no cold loss.

Other precautions are. Together with the time delay in the analysis, the once formed solid acetylene does not dissolve easily. Hence, even though it is diluted with the addition of more liquid oxygen, it takes a considerably longer time to redissolve the solid and to attain a homogeneous concentration.

The cause of accident No. 1, Table 11 (occurred abroad) was: The acetylene, which was expelled from the filter by the warm air at the starting of the plant six months previously, temporarily accumulated inside the reboiler. Despite six months of operation, the initial state presumably still partially remained in the system.

Another accident was caused because of the malfunction of the cold accumulator. Warm air temporarily entered and expelled the absorbed acetylene from the filter, which flowed into the reboiler and solidified. The presence of solid acetylene was not detected by the analysis. It is necessary to provide several sampling ports for their detection.

A new silica-gel must be used at the start, and in case of a malfunction. Also, it is necessary to conduct more frequent analyses.

Concurrently, an infrared analyzer is being developed; total hydrocarbon content in the source air is oxidized to $CO_2$ by a catalyst which is continuously and automatically analyzed. Figure 10 [10] shows the chart indicating the operational cycle of the analyzer. /28

The installation of such a analyzer in the air separation plant to make the instrument give a warning, when the total hydrocarbon content

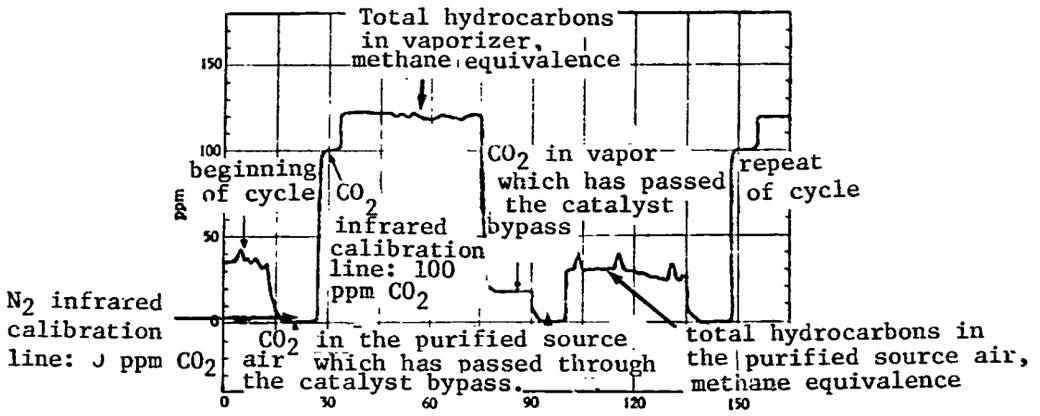


Figure 10. The analysis chart indicating the operational cycle.

reaches the stop limit, appears to be very effective. Nevertheless, since there are no concrete data which correlate the total hydrocarbon content to the acetylene content, and also, since it is conceivable that the acetylene content may increase independently, an independent analysis for acetylene is important.

### 6.2.6 Conclusion

In summary, it can be concluded that all the accidents which occurred in the reboiler can be attributed to hydrocarbons which are mainly composed of acetylene. Although the ignition source is unknown, this type of accident can be prevented by installing various kinds of filters in the path to the reboiler in order to remove the above inflammable impurities.

Nevertheless, the concentration of pollutants in the atmosphere varies with time depending on the surrounding conditions. Also, the functions of the various filtering devices vary according to the operational condition of the entire plant. Hence, the filters must be controlled in response to

the varying impurity concentration in the intake air, and to the operating conditions of the plant. At the present, the time delay in obtaining the analytical results appears to be inevitable in some cases. In view of such a problem, the development of an automatic continuous analyzer is necessary. As a countermeasure, an effective method is to set the alarm limit to a lower concentration. At any rate, extra precautions must be exercised against the exhaust gases of the nearby plants, and the desorption of gases in the acetylene filters at the times of heating, starting, and malfunctioning. Also, in connection with the discharging of liquid oxygen when the operation is halted, such action should be taken after the liquid in the lower column has been all transferred to the upper column, thereby diluting the concentration in the reboiler.

Accidents which occurred elsewhere are attributed either to the diffusion of lubricating oil into the paths in the plant, or to the contact of inflammable materials with liquid oxygen. Therefore, oils adhering to the inside and outside of the plant must be washed periodically with a proper detergent to prevent their accumulation. The detergent must be removed completely. Needless to say, safety controls should be enforced with common sense, ensuring that accidents do not occur from something very fundamental as a result of excessive attention being given to other details.

### 6.2.7 Future Problems

#### (1) Hazardous substances other then acetylene

Although in the foregoing the fuels causing the accidents were presumed to be hydrocarbons comprised mostly of acetylene, with our present knowledge, the functions of other hazardous substances are not known. Future studies, therefore, are needed.

#### (2) Solubilities of other hazardous substances in liquid oxygen and liquid air.

Since the accumulation of acetylene and other contaminants in liquid oxygen beyond their solubility limits is directly connected to the hazard of explosion, it is of primary importance to obtain their solubilities. At present, the numbers from various sources do not agree.

(3) Development of an automatic continuous microanalyzer

Although a discussion of the analyzer for the total hydrocarbon content was given, the development of a continuous microanalyzer for acetylene is awaited, since the fraction that is acetylene is not constant. It can continuously analyze the amount of acetylene in the source air, in the acetylene filter, and in the reboiler and give a warning when it reaches the limit. This would ensure an extremely safe operation.

(4) Since explosions occurring at low temperatures, such as in the reboiler, have different causes unlike ordinary explosions, studies are needed to establish the mechanism. Also, in place of the silica-gel used in the acetylene filter, there may exist an oxidant for hydrocarbons at low temperatures.

## 6.3 Causes of Bursting Accidents and Countermeasures

### 6.3.1 Accidents Caused by Poor Design or Manufacture

Bursting which occurs even during operation below the design pressure belongs to this catagory.

Although the thicknesses of the container and the pipe are calculated according to the regulations, caution must be exercised in purchasing and using materials which are suitable for the design strength.

Even though steel is frequently used in the low temperature part of /29

the precooler, consideration must be given to low temperature brittleness and to thermal stress.

Aluminum steel, and low nickel steel have superior properties at low temperatures. The welded parts must be annealed to remove the stress. Since there are cases where bursting occurred at the welded part of the precooler, the welding method and the inspection of the welded parts are important (No. 2, 3, Table 9).

6.3.2 Accidents Caused by Operational Error

In operating the air separation plant, care must always be taken to maintain the pressure in the plant at a proper design pressure, and the manipulation of valves must be performed slowly while observing the pressure gauge. Especially since the pressure in the liquefaction column rises abruptly due to the inflow of high pressure, one must be very careful. (No. 4, Table 9).

Since the expansion valve, and the control valve can be easily clogged by the gradual accumulation of solid carbon dioxide causing the pressure to rise, whenever such a tendency is detected, the solids must be removed by opening and closing the valve a few times.

In preparation for emergencies, safety valves must be installed wherever the pressure may tend to rise. These valves must be tested beforehand and periodically tested afterwards to ensure that they are operative (No. 5, Table 9).

Although the adjustment of operating pressure is vitally important in the operation to prevent burstings, there are cases where the bursting of pipes occurred due to the freezing of the soda purifying column liquid entering the precooler. This is one of the examples of operational error (No. 1, Table 9).

## 6.4 Cause of Human Accidents and Countermeasures

Aside from those indicated in the previous section, human accidents include all disasters inflicted on the workers. Many of these accidents are caused by a lack of safety precautions and training on the part of the supervisor or the workers. Therefore, the most important countermeasure against these accidents is the training of not only the assigned workers but, also, of those who enter as repairmen to ensure the safety required in operating the air separation plant.

### 6.4.1 Burns

This type of injury is attributed to the property of oxygen to promote combustion. It is the most typical human accident encountered in the operation of the air separation plant. When clothes catch fire during welding in a high oxygen concentration environment, the entire body will be engulfed in flames before there is time to extinguish them. As a result, the whole body will suffer severe burns which may lead to death.

Whenever liquid oxygen is being discharged near the separation plant or being filled in containers, the oxygen concentration is very likely to be extremely high in the vicinity. Especially, since cold oxygen is heavier than air and tends to accumulate in the low regions, it is dangerous to be inside the pit. In such an environment, clothes can even catch fire from electrostatic sparks. Precautions must be taken inside the pit leading to the oxygen pipes and the holder, since sometimes, the oxygen concentration may be high due to a leak. Especially when pipes are being disconnected for repair, utmost care must be exercised.

In order to prevent such accidents, the area which is suspected of being high in oxygen content must be thoroughly ventilated before entering. Providing water sprinklers is one of the countermeasures.

6.4.2 Frostbite and Death from Cold

The temperature inside the separation plant is extremely low as oxygen is being liquefied. Whenever liquid air and liquid oxygen are being handled, gloves must be worn for protection, since they can cause severe frostbite. Although it is rare, the low temperature air which has leaked out may accumulate in the pit and bring about death (No. 14, Table 10).

6.4.3 Suffocation

In the air separation plant, precautions must be taken against suffocation. This is caused by nitrogen discharged from the plant, or the dry nitrogen used in the outer tank as a protective gas.

When entering the outer tank for repair work while nitrogen is being introduced, either a respirator must be worn or the oxygen content must be analyzed.

When the plant is being heated, staying in the vicinity of the blow valve from which nitrogen is being discharged may cause suffocation. Especially /30
when it is being blown high above the ground (such as at the safety valve, the outlet of the cold accumulator and the muffler) precautions must be taken because of the danger of falling.

When the oxygen concentration in the air falls below 15%, there is a danger of suffocation. It must be remembered that when one is stricken with suffocation, he will become unconscious without experiencing pain (No. 5, Table 10).

## 7. CONCLUSION

As indicated in the preface, the objective of this survey was to collect

the records of accidents. Among the records of accidents which occurred in this country, those which had been reported to the Ministry of International Trade and Industry were collected. They were analyzed, arranged, classified into various types, and tabulated for review.

Accidents at air separation plants began in 1930. Up to 1950, experience and knowledge about the disasters (mainly explosions) at the air separation plant were lacking. Therefore, most of the causes were attributed to the formation of copper acetylene by the reaction of acetylene and copper which was mainly employed in the liquefaction column. The records of accidents whose causes were clearly known to be erroneously reported were corrected. A chapter was dedicated to the causes and the countermeasures of the accidents, and discussions were presented based on the knowledge of this country and foreign countries.

We will feel very fortunate if this survey contributes in some way towards establishing a technological standard, or towards preventing accidents at the air separation plants.

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# APPENDIX

## TABLES OF AIR SEPARATION PLANTS IN JAPAN

(as of October, 1962)

TABLE OF AIR SEPARATION PLANTS IN JAPAN

| Company, Plant | Date of Install. | Type | Capacity ($m^3/h$) | No. | Manufacturer | Operating Conditions | | | | Purpose |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Operating | Temporarily resting | Resting | Removed | |
| Yawata Iron Works, Yawata | 5/53 | Hitachi Kaken Type, Total Low Pressure | $O_2$ 99.6 450 | 1 | Hitachi Mfg. | | S-37 | | | Solvent |
| | 5/54 | Linde Frankel | $O_2$ 99.6 2,000 | 1 | Kobe Steel | | S-37 | | | Open Hearth Revolving Furnace |
| | 12/57 | New Linde Frankel | $O_2$ 99.6 4,250 $N_2$ 99,9 500 | 1 | Linde | 0 | | | | Rev.Fur. |
| | 7/58 | Hitachi Kaken Type, Tot. Low Press. | $O_2$ 99.6 4,500 $N_2$ 99.99 3,000 | 1 | Hitachi Mfg. | 0 | | | | Rev.Fur. |
| | 9/61 | Hitachi Kaken Type, Tot. Low Press. | $O_2$ 99.6 6,000 $N_2$ 99.99 6,000 | 1 | Hitachi Mfg. | 0 | | | | Rev.Fur. |

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TABLE OF AIR SEPARATION PLANTS IN JAPAN

| Company, Plant | Date of Install. | Type | Capacity ($m^3/h$) | No. | Manufacturer | Operating Conditions | | | | Purpose |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Operating | Temporarily resting | Resting | Removed | |
| | 7/62 | Hitachi Kaken Type, Total Low Pressure | $O_2$ 99.6 6,000<br>$N_2$ 99.99 6,000 | 1 | Hitachi Mfg. | 0 | | | | Rev.Fur. |
| Tobata | 8/59 | Hitachi Kaken Type, Total Low Pressure | $O_2$ 99.6 4,500<br>$N_2$ 99.99 3,000 | 1 | Hitachi Mfg. | 0 | | | | Rev.Fur. |
| | 8/60 | Hitachi Kaken Type, Total Low Pressure | $O_2$ 99.6 4,500<br>$N_2$ 99.99 3,000 | 1 | Hitachi Mfg. | 0 | | | | Rev.Fur. |
| | 11/60 | Hitachi Kaken Type, Total Low Pressure | $O_2$ 99.6 4.500<br>$N_2$ 99.99 3,000 | 1 | Hitachi Mfg. | 0 | | | | Rev.Fur. |

TABLE OF AIR SEPARATION PLANTS IN JAPAN

| Company, Plant | Date of Install. | Type | Capacity ($m^3/h$) | No. | Manufacturer | Operating Conditions | | | | Purpose |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Operating | Temporarily resting | Resting | Removed | |
| | 3/62 | Hitachi Kaken Type, Total Low Pressure | $O_2$ 99.6 6,000<br>$N_2$ 99.99 6,000 | 1 | Hitachi Mfg. | 0 | | | | Rev.Fur. |
| | 4/62 | Hitachi Kaken Type, Total Low Pressure | $O_2$ 99.6 6,000<br>$N_2$ 99.99 6,000 | 1 | Hitachi Mfg. | 0 | | | | Rev.Fur. |
| Kawasaki Iron Works | 8/55 | Linde Frankel | $O_2$ 99.5 2,000 | 1 | Nippon Rika | 0 | | | | Open Hearth |
| | 7/58 | New Linde Frankel | $O_2$ 99.5 3,000 | 1 | Nippon Rika | 0 | | | | Open Hearth |
| | 4/60 | New Linde Frankel | $O_2$ 99.5 4,200 | 1 | Nippon Rika | 0 | | | | Open Hearth |
| | 6/61 | New Linde Frankel | $O_2$ 99.5 4,200 | 1 | Nippon Rika | 0 | | | | Open Hearth |
| | 10/62 | New Linde Frankel | $O_2$ 99.5 4,200 | 1 | Nippon Rika | 0 | | | | Rev.Fur. |

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TABLE OF AIR SEPARATION PLANTS IN JAPAN

| Company, Plant | Date of Install. | Type | Capacity ($m^3/h$) | No. | Manufacturer | Operating Conditions | | | | Purpose |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Operating | Temporarily resting | Resting | Removed | |
| Fukiai | 1/52 | Linde Frankel | $O_2$ 98.0 2,000 | 1 | Nippon Rika | 0 | | | | Open Hearth |
| Nishinomiya | 7/52 | Highland Compounded | $O_2$ 99.8 100 | 1 | Nippon Rika | 0 | | | | Reclining Electric Furnace |
| Amagasaki Iron Works, Amagasaki | 5/52 | Linde Med. Pressure, Ammonia Cycle | $O_2$ 99.5 500 | 1 | Kobe Steel | 0 | | | | Welding Cutting |
| | 8/60 | Shinko Total Low Pressure, Middle Extraction | $O_2$ 99.5 3,000 | 1 | Kobe Steel | 0 | | | | Rev.Fur. |
| Nippon Satetsu, Shikama | 12/57 | LOCECV Type, Horizontal Single Cylinder | $O_2$ 99.9 135 | 1 | Liquid Oxygen Machineries | | | | S-37 | Reclining Electric Furnace |
| | 6/59 | Claude | $O_2$ 99.9 200 | 1 | Teikoku Oxygen | | | | S-37 | Rec. Elec. Fur. |

TABLE OF AIR SEPARATION PLANTS IN JAPAN

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|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Operating | Temporarily resting | Resting | Removed | |
| Nippon Steel, Muroran | 12/53 | Claude | $O_2$ 99.6 500 | 1 | Teikoku Oxygen | 0 | | | | Open Hearth |
| | 4/62 | Claude | $O_2$ 99.6 500 | 1 | Mitsubishi Kakoki | 0 | | | | Open Hearth |
| Tokai Iron Works, Nagoya | 1961 | 11,000 TO | $O_2$ 99.6 11,000 | 1 | Hitachi Seisaky | Under construction | | | | Steel |
| | | | $N_2$ 99.995 10,000 | | | | | | | |
| Nisshin Steel, Kure | 12/60 | NR-8 Total Low Press. | $O_2$ 99.7 1,000 | 1 | Nippon Rika | 0 | | | | Open Hearth |
| Amagasaki | 11/60 | NR-4 Total Low Press. | $O_2$ 99.7 500 | 1 | Nippon Rika | 0 | | | | Rec. Elec. Fur. |
| Tekko Co., Sakata | 1945 | Highland | $N_2$ 400 | 1 | Nippon Rika | Assist only when Claude is resting | | | | $N_2$, $O_2$ Sales |
| | 1949 | Claude | $N_2$ 500 | 1 | Mitsubishi Kakoki | 0 | | | | |

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| Company, Plant | Date of Install. | Type | Capacity ($m^3/h$) | No. | Manufacturer | Operating Conditions | | | | Purpose |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Operating | Temporarily resting | Resting | Removed | |
| Aichi Steel, Chita | 10/53 | Highland | $O_2$ 99.0 75 | 1 | Nippon Rika | O | | | | Open Hearth |
| Kariya | 1953 | Highland | $O_2$ 99.0 35 | 1 | Nippon Rika | O | | | | Elec. Rec. Fur. |
| Fuji Steel, Muroran | 1/54 | Claude | $O_2$ 99.7 500 | 1 | Mitsubishi Kakoki | | | | S-37 | |
| | 10/58 | Total Low Pressure Linde Frankel | $O_2$ 99.6 4,500 | 1 | Kobe Steel | O | | | | Open Hearth |
| | 6/61 | Total Low Pressure | $O_2$ 99.6 10,000 | 1 | Hitachi Mfg. | O | | | | Rev.Fur. High Fur. |
| Kamaishi | 5/54 | M.K.P. 2,800 | $O_2$ 99.7 500 | 1 | Nippon Rika | O | | | | Open Hearth High Fur. |
| | 4/62 | Total Low Pressure Type | $O_2$ 99.6 4,500 | 1 | Nippon Rika | O | | | | High Fur. |

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| Company, Plant | Date of Install. | Type | Capacity ($m^3/h$) | No. | Manufacturer | Operating Conditions | | | | Purpose |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Operating | Temporarily resting | Resting | Removed | |
| Fuji Steel, Hirohata | 1/55 | Total Low Pressure Linde Frankel | $O_2$ 99.6 3,000 | 1 | Kobe Steel | | S-37 | | | Op. Hear. Rev.Fur. High Fur. |
| | 1/59 | Tot. Low Press. Linde Frankel | $O_2$ 99.6 4,000 | 1 | Kobe Steel | 0 | | | | Opn. Hear. Rev.Fur. High Fur. |
| | 3/61 | Tot. Low Press. Linde Frankel | $O_2$ 99.6 10,000 | 1 | Kobe Steel | 0 | | | | Opn.Hear. Rev.Fur. High Fur. |
| Daido Steel, Hoshizaki | 1/52 | Claude Type PAC | $O_2$ 99.2 80 | 1 | Teikoku Oxygen | 0 | | | | Recl. Elec. Fur. |
| | 12,57 | Claude Type PA | $O_2$ 99.8 245 | 1 | Teikoku Oxygen | 0 | | | | Recl. Elec. Fur. |
| Chita | 12/62 | uA-500 | $O_2$ 99.6 500 | 1 | Teikoku Oxygen | 0 | | | | scarhing (sic) |

TABLE OF AIR SEPARATION PLANTS IN JAPAN

| Company, Plant | Date of Install. | Type | Capacity ($m^3/h$) | No. | Manufacturer | Operating Conditions | | | | Purpose |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Operating | Temporarily resting | Resting | Removed | |
| Mitsubishi Steel, Hirota | 1952 | Messer | $O_2$ 99.7 30 | 1 | Messer Schmidt | 0 | | | | Recl. Elec.Fur. |
| Nippon Special Steel, Omori | 12/61 | Highland | $O_2$ 99.5 30 | 1 | Togo Mfg. | | | S-1961 | | Recl. Elec.Fur. |
| Sumitomo Metal Wakayama | 2/61 | MNRD 18Type | $O_2$ 99.5 3,000 | 1 | Nippon Rika | 0 | | | | Open Hearth Scarhing (sic) |
| Kokura | 5/56 | Total Low Pressure Middle Extraction Method | $O_2$ 95 400 | 1 | Hitachi Mfg. | | S-9/60 | | | Open Hearth High Fur. |
| Nippon Steel Pipe, Kawasaki | 3/53 | Linde Frankel | $O_2$ 99.5 2,000 | 1 | Nippon Rika | 0 | | | | Opn.Hear. Rev.Fur. /35 |
| | 1/58 | Modified Linde Frankel | $O_2$ 99.5 4,250 | 1 | Linde | 0 | | | | Opn.Hear. Rev.Fur. |

TABLE OF AIR SEPARATION PLANTS IN JAPAN

| Company, Plant | Date of Install. | Type | Capacity ($m^3/h$) | No. | Manufacturer | Operating Conditions | | | | Purpose |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Operating | Temporarily resting | Resting | Removed | |
| Tsurumi | 6/61 | Hitachi Total Low Press. TO | $O_2$ 99.6 3,000 | 1 | Hitachi Mfg. | 0 | | | | High Fur. Opn.Hear. |
| Mizue | 12/59 | Total Low Press. Heat Regeneration Circuit | $O_2$ 99.5 4,500 | 1 | Hitachi Mfg. | 0 | | | | Rev.Fur. Annealing |
| | 1/61 | Total Low Pressure Middle Extraction | $O_2$ 99.5 4,500<br>$N_2$ 99.99 4,500 | 1 | Hitachi Mfg. | 0 | | | | Cold Separation |
| | 7/63 | Total Low Pressure Middle Extraction | $O_2$ 99.5 4,500<br>$N_2$ 99.99 4,500 | 1 | Hitachi Mfg. | 0 | | | | Others |
| Kobe Steel, Kobe | 1944 | OE | 120 $M^3$ $O_2$ Manufacturing apparatus | 1 | Kobe Steel | 0 | | | S-1955 | |
| | 2/50 | Linde | $O_2$ 99.5 250 | 1 | Kobe Steel | | | S-11/1961 | | |

TABLE OF AIR SEPARATION PLANTS IN JAPAN

| Company, Plant | Date of Install. | Type | Capacity ($m^3/h$) | No. | Manufacturer | Operating Conditions | | | | Purpose |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Operating | Temporarily resting | Resting | Removed | |
| | 2/51 | OF | $O_2$ 99.5 2,000 | 1 | Kobe Steel | | | S-5/ 1962 | | |
| | 6/59 | OF | $O_2$ 99.5 2,000 | 1 | Kobe Steel | 0 | | | | Opn.Hear. Recl. Elec.Fur. |
| | 2/62 | OF | $O_2$ 99.6 6,500 $N_2$ 99.99 2,000 | 1 | Kobe Steel | 0 | | | | Rev.Fur. Pot Scarhing (sic) |
| Nakayama Steel, Funa-machi | 6/57 | Hitachi Kaken Type Total Low Pressure | $O_2$ 98 2,000 ($O_2$ 99.5 1,700) | 1 | Hitachi Mfg. | 0 | | | | Opn.Hear. |
| | 1/60 | Hitachi Total Low Press. Type | $O_2$ 98 2,000 ($O_2$ 99.5 1,700) | 1 | Hitachi Mfg. | 0 | | | | Opn.Hear. |

TABLE OF AIR SEPARATION PLANTS IN JAPAN

| Company, Plant | Date of Install. | Type | Capacity ($m^3/h$) | No. | Manufacturer | Operating Conditions | | | | Purpose |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Operating | Temporarily resting | Resting | Removed | |
| Sanyo Steel | 10/43 | Highland | $O_2$ 99.5 60 | 1 | Tanaka Ind. | | S-1962 | | | Recl. Elec.Fur. |
| Daiwa Steel, Osaka | 1/60 | Linde Frankel | $O_2$ 99.7 500 | 1 | Kobe Steel | | S-8/62 | | | Opn.Hear. |
| Osaka Steel, Nishijima | 4/52 | Linde | $O_2$ 99.6 500 | 1 | Kobe Steel | | S-1960 | | | High Fur. Opn.Hear. |
| | 4/60 | Shinko Total Low Pressure | $O_2$ 99.6 3,000 | 1 | Kobe Steel | 0 | | | | High Fur. Opn.Hear. |
| Nippon Hydrogen, Onahama | 1953 | Linde Frankel | $O_2$ 98.0 1,500<br>$N_2$ 99.5 100 | 1 | Kobe Steel | | S-9/62 | | | Ammonia Methanol |
| | 1955 | Linde Frankel | $O_2$ 99.0 2,000<br>$O_2$ 99 9 200<br>$N_2$ 99.6 3,300 | 1 | Nippon Rika | 0 | | | | Ammonia Methanol |

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TABLE OF AIR SEPARATION PLANTS IN JAPAN

| Company, Plant | Date of Install. | Type | Capacity ($m^3/h$) | No. | Manufacturer | Operating Conditions | | | | Purpose |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Operating | Temporarily resting | Resting | Removed | |
| | 1957 | Total Low Press. | $O_2$ 99.5 4,000<br>$N_2$ 99.9 7,000 | 1 | Kobe Steel | 0 | | | | Ammonia Methanol |
| Osaka Oxygen, Fukuoaka | 4/58 | Highland | L.$O_2$ 99.7 1,000<br>L.$N_2$ 99.999 250 | 1 | Nippon Rika | 0 | | | | $O_2N_2$ |
| Himeji | 10/57 | Airpro | L.$O_2$ 99.7 800<br>G.$N_2$ 99.999 60<br>Ar 99.99 20 | 1 | U.S. Air Prod. | 0 | | | | $O_2N_2$ Ar |
| | 9/61 | Highland | L.$O_2$ 99.7 1,500<br>L.$N_2$ 99.999 500<br>Ar 99.99 30 | 1 | Kobe Steel | 0 | | | | $O_2N_2$ Ar |

TABLE OF AIR SEPARATION PLANTS IN JAPAN

| Company, Plant | Date of Install. | Type | Capacity ($m^3/h$) | No. | Manufacturer | Operating Conditions | | | | Purpose |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Operating | Temporarily resting | Resting | Removed | |
| Amagasaki | 5/54 | Airpro | $L.O_2$ 99.7 800<br>$G.N_2$ 99.999 60<br>Ar 20 | 1 | U.S. Air Prod. | 0 | | | | $O_2N_2$ Ar |
| | 4/57 | Airpro | $L.O_2$ 99.7 800<br>$G.N_2$ 99.999 60<br>Ar 20 | 1 | U.S. Air Prod. | 0 | | | | $O_2N_2$ Ar |
| | 8/59 | Messer | $G.O_2$ 99.7 500 | 1 | Kobe Steel | | 0 | | | $O_2$ |
| Nissan Chem., Toyama | 1938 | Linde | $O_2$ 93 - 96 350 | 2 | Linde | 0 | | | | Chemical |
| | 1948 | Linde | $O_2$ 95 - 97 300<br>$N_2$ 99.9 1,100 | 1 | Mitsubishi Kakoki | 0 | | | | Chem. |

TABLE OF AIR SEPARATION PLANTS IN JAPAN

| Company, Plant | Date of Install. | Type | Capacity ($m^3/h$) | No. | Manufacturer | Operating Conditions | | | | Purpose |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Operating | Temporarily resting | Resting | Removed | |
| | 1949 | Linde | $O_2$ 95 - 97 300<br>$N_2$ 99.9 1,100 | 1 | Mitsubishi K Kakoki | 0 | | | | Chem. |
| | 1952 | Linde | $O_2$ 95 - 97 300<br>$N_2$ 99.9 1,100 | 1 | Nippon Rika | 0 | | | | Chem. |
| | 1943 | Linde | $O_2$ 95 - 97 300<br>$N_2$ 99.9 1,100 | 1 | Nippon Rika | 0 | | | | Chem. |
| | 1952 | Linde | $O_2$ 95 - 97 300<br>$N_2$ 99.9 1,100 | 1 | Nippon Rika | 0 | | | | Chem. |
| Nagaoka | 1953 | Linde | $O_2$ 95 - 97 300<br>$N_2$ 99.9 1,100 | 1 | Nippon Rika | 0 | | | | Chem. |

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TABLE OF AIR SEPARATION PLANTS IN JAPAN

| Company, Plant | Date of Install. | Type | Capacity ($m^3/h$) | No. | Manufacturer | Operating Conditions | | | | Purpose |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Operating | Temporarily resting | Resting | Removed | |
| | 1957 | Total Low Press. | $O_2$ 98 2,000<br>$N_2$ 99.9 2,000 | 1 | Nippon Rika | 0 | | | | Chem. |
| Nagaoka | 1959 | Total Low Press. 3,000-T O | $O_2$ 98 3,000<br>$N_2$ 99.99 4,700 | 1 | Hitachi Mfg. | 0 | | | | Chem. |

TABLE OF AIR SEPARATION PLANTS IN JAPAN

| Company, Plant | Date of Install. | Type | Capacity ($m^3/h$) | No. | Manufacturer | Operating Conditions | | | | Purpose |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Operating | Temporarily resting | Resting | Removed | |
| Sumitoma Chem. | 1947 | Linde | $N_2$ 2,000 | 1 | Mitsubishi Kakoki | | | | S-1957 | Ammonium Sulfate |
| | 1948 | Linde | $N_2$ 2,000 | 1 | Mitsubishi Kakoki | | | | S-1957 | Ammonium Sulfate |
| | 1953 | Total Low Pressure Linde Frankel | $O_2$ 98.6 3,000<br>$N_2$ 99.7 4,500 | 1 | Nippon Rika | 0 | | | | Ammonium Sulfate |
| | 1958 | Total Low Press. Linde Frankel | $O_2$ 98.6 3,000<br>$N_2$ 99.7 4,500 | 1 | Nippon Rika | 0 | | | | Ammonium Sulfate |
| | 1959 | Total Low Press. Linde Frankel | $O_2$ 98.6 3,000<br>$N_2$ 99.7 5,000 | 1 | Nippon Rika | 0 | | | | Ammonium Sulfate |
| | 1961 | Total Low Press. Linde Frankel | $O_2$ 98.6 3,200<br>$N_2$ 99.7 6,000 | 1 | Nippon Rika | 0 | | | | Ammonium Sulfate |

TABLE OF AIR SEPARATION PLANTS IN JAPAN

| Company, Plant | Date of Install. | Type | Capacity ($m^3/h$) | No. | Manufacturer | Operating Conditions | | | | Purpose |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Operating | Temporarily resting | Resting | Removed | |
| Toa Gosei, Nagoya | 1933 | Claude | $O_2$ 99.1 170<br>$N_2$ 99.9 830 | 1 | Rail Liquid | | | S-1961 | | Ammonia |
| | 1937 | Messer | $O_2$ 94 530<br>$N_2$ 99.9 1,920 | 1 | Nippon Rika | 0 | | | | Ammonia |
| | 1943 | Claude | $O_2$ 98.9 520<br>$N_2$ 99.9 2,250 | 2 | Teikoku Oxygen | 0 | | | | Ammonia |
| | 1955 | Linde Frankel | $O_2$ 99 1,500<br>$N_2$ 99.9 3,000 | 1 | Kobe Steel | 0 | | | | Ammonia |
| | 12/61 | Highland | L.$O_2$ 99.8 1,200 | 1 | Nippon Rika | 0 | | | | Ammonia |

TABLE OF AIR SEPARATION PLANTS IN JAPAN

| Company, Plant | Date of Install. | Type | Capacity ($m^3/h$) | No. | Manufacturer | Operating Conditions | | | | Purpose |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Operating | Temporarily resting | Resting | Removed | |
| Agahi Kasei, Nobeoka | 1948 | Claude | $N_2$ 500 | 1 | Teikoku Oxygen | 0 | | | | Ammonia |
| | 1948 | Claude | $N_2$ 500 | 2 | Mitsubishi Kakoki | 0 | | | | Ammonia |
| | 1959 | TO-1,500 | $O_2$ 98 1,500<br>$O_2$ 99.5 100<br>$N_2$ 99.99 2,600 | 1 | Hitachi Mfg. | 0 | | | | Ammonia |
| Toyo Oxygen, Kawasaki | 4/55 | Messer | $O_2$ 99.7 400 | 1 | Messer Co. | 0 | | | | Ammonia |
| | 9/57 | Nippon Rika | $O_2$ 99.7 1,200<br>$N_2$ 99.999 250 | 1 | Nippon Rika | 0 | | | | Ammonia |
| Toyo Oxygen, Kawasaki | 8/60 | Nippon Rika | $O_2$ 99.7 1,200<br>$N_2$ 99.999 200 | 1 | Nippon Rika | 0 | | | | |

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TABLE OF AIR SEPARATION PLANTS IN JAPAN

| Company, Plant | Date of Install. | Type | Capacity ($m^3/h$) | No. | Manufacturer | Operating Conditions | | | | Purpose |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Operating | Temporarily resting | Resting | Removed | |
| Toyo Oxygen (con't) | | | Ar 99.999 28 | | | | | | | |
| | 3/62 | Linde Frankel | $O_2$ 99.7 2,400<br>$N_2$ 99.999 500<br>Ar 99.999 50 | 1 | Nippon Rika | 0 | | | | |
| Mitsubishi Kasei, Kurosaki | 1936 | Linde Frankel | $O_2$ 98 2,750<br>$N_2$ 99 100 | 1 | Linde | 0 | | | | Ammonia |
| | 1950 | Linde Frankel | $O_2$ 98 2,750<br>$N_2$ 99 100 | 1 | Kobe Steel | 0 | | | | Ammonia |
| Toyo Soda, Tokuyama | 1960 | 350 F 49 NF | $O_2$ 98 3,300<br>$O_2$ 98.5 200<br>$N_2$ 99.99 4,900 | 1 | Kobe Steel | 0 | | | | Ammonium Sulfate |

TABLE OF AIR SEPARATION PLANTS IN JAPAN

| Company, Plant | Date of Install. | Type | Capacity ($m^3/h$) | No. | Manufacturer | Operating Conditions | | | | Purpose |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Operating | Temporarily resting | Resting | Removed | |
| Nippon Carbide, Uotsu | 1/47 | Claude | $O_2$ 99.3 400<br>$N_2$ 99.95 2,000 | 1 | Teikoku Oxygen | 0 | | | | Lime Nitrogen |
| | 2/51 | Linde | $N_2$ 99.9 1,350 | 1 | Mitsubishi Kakoki | 0 | | | | Lime Nitrogen |
| | 1951 | Linde | $N_2$ 900 | 1 | Linde | | | | S-1962 | Lime Nitrogen |
| | 3/62 | Claude | $O_2$ 99.5 400<br>$N_2$ 99.99 2,000 | 1 | Teikoku Oxygen | 0 | | | | Lime Nitrogen |
| Kahikawa Elec., Ogaki | 11/48 | Air Liquefaction Separator | $O_2$ 80<br>$N_2$ 400 | 1 | Nippon Rika | 0 | | | | Lime Nitrogen |
| | 5/51 | Air Liquefaction Separator | $O_2$ 150<br>$N_2$ 1,000 | 1 | Nippon Rika | 0 | | | | Lime Nitrogen |
| Seitetsu Chem., Beppu | 1952 | Linde Frankel | $O_2$ 98 1,200 | 1 | Kobe Steel | | | S-1962 | | Lime Nitrogen |

TABLE OF AIR SEPARATION PLANTS IN JAPAN

| Company, Plant | Date of Install. | Type | Capacity ($m^3/h$) | No. | Manufacturer | Operating Conditions | | | | Purpose |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Operating | Temporarily resting | Resting | Removed | |
| | 1958 | TO-4,000 | $O_2$ 99.2 4,000<br>$N_2$ 99.9 4,500 | 1 | Hitachi Mfg. | 0 | | | | Fertilizer |
| Himeji | 1956 | TO-1,500 | $O_2$ 98 1,500 | 1 | Hitachi Mfg. | 0 | | | | Chem. |
| Toyo High Press., Hokkaido | 1943 | Linde Frankel | $O_2$ 95 3,000 | 1 | Kobe Steel | 0 | | | | Ammonia |
| | 1948 | Linde Frankel | $O_2$ 95 3,000 | 1 | Kobe Steel | 0 | | | | Ammonia |
| | 1951 | Linde Frankel | $O_2$ 95 3,000<br>$N_2$ 99.5 4,000 | 1 | Kobe Steel | 0 | | | | Ammonia |
| | 1958 | New Linde Frankel | $O_2$ 98.7 3,000<br>$N_2$ 99.99 6,000 | 1 | Kobe Steel | 0 | | | | Ammonia |
| Chiba | 1957 | New Linde Frankel | $O_2$ 98 1,200 | 1 | Kobe Steel | 0 | | | | Methano |

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TABLE OF AIR SEPARATION PLANTS IN JAPAN

| Company, Plant | Date of Install. | Type | Capacity ($m^3$/h) | No. | Manufacturer | Operating Conditions | | | | Purpose |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Operating | Temporarily resting | Resting | Removed | |
| | 1958 | New Linde Frankel | $O_2$ 98 2,400<br>$N_2$ 99.99 4,000 | 1 | Kobe Steel | 0 | | | | Ammonia |
| | 1960 | New Linde Frankel | $O_2$ 97 3,300<br>$N_2$ 99.998 5,000 | 1 | Kobe Steel | 0 | | | | Ammonia |
| | 1961 | New Linde Frankel | $O_2$ 97 2,650<br>$N_2$ 99.998 3,000 | 1 | Kobe Steel | 0 | | | | Methanol |
| Omuda | 1935 | Claude | $O_2$ 260<br>$N_2$ 900 | 1 | Rail Liquid | | | S-1961 | | Ammonia |
| | 1934 | Claude | $O_2$ 260<br>$N_2$ 900 | 1 | Rail Liquid | | | S-1961 | | Ammonia |
| | 1937 | Claude | $O_2$ 800<br>$N_2$ 2,800 | 1 | Rail Liquid | 0 | | | | Ammonia |

TABLE OF AIR SEPARATION PLANTS IN JAPAN

| Company, Plant | Date of Install. | Type | Capacity ($m^3/h$) | No. | Manufacturer | Operating Conditions | | | | Purpose |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Operating | Temporarily resting | Resting | Removed | |
| | 1961 | New Linde Frankel | $O_2$ 97 5,500<br>$N_2$ 99.99 7,000 | 1 | Kobe Steel | 0 | | | | Ammonia |
| Shinnippon Nitrogen, Mizumata | | Claude | $N_2$ 99.9 760 | 3 | Teikoku Oxygen | 0 | | | | Ammonia |
| | | Claude | $N_2$ 99.9 800 | 1 | Nicchitsu | 0 | | | | Ammonia |
| | | Claude | $N_2$ 99.8 760 | 2 | Teikoku Oxygen | 0 | | | | Ammonia |
| | 1958 | MC-1750 | $N_2$ 99.95 1,350 | 1 | Nippon Rika | 0 | | | | Ammonia |
| Ube K ean, Ube | 10/33 | Linde | $N_2$ 99.9 1,000 | 4 | Linde | | | S-9/ 1962 | | Ammonium Sulfate |
| | 1937 | Linde | $N_2$ 99.9 2,000 | 2 | Linde | | | | S-7/ 1962 | Ammonium Sulfate |
| | 1947 | Linde | $N_2$ 2,000 | 1 | Mitsubishi Kakoki | | | S-9/ 1062 | | Ammonium Sulfate |

TABLE OF AIR SEPARATION PLANTS IN JAPAN

| Company, Plant | Date of Install. | Type | Capacity ($m^3/h$) | No. | Manufacturer | Operating Conditions | | | | Purpose |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Operating | Temporarily resting | Resting | Removed | |
| Ube Kosan, Ube | 1948 | Linde | $N_2$ 2,000 | 1 | Mitsubishi Kakoki | | | S-9/ 1962 | | Ammonium Sulfate |
| | 1958 | O F | $O_2$ 98 4,000<br>$N_2$ 99.99 6,000 | 1 | Kobe Steel | O | | | | Ammonium Sulfate |
| | 1961 | O F | $O_2$ 9[illegible] 6,700<br>$O_2$ 99.6 200<br>$N_2$ 99.99 11,000 | 1 | Kobe Steel | O | | | | Ammonium Sulfate |
| Nippon Oxygen, Kawasaki | 12/53 | Highland | $O_2$ 99.8 500<br>$N_2$ 99.99 50 | 2 | Nippon Rika | O | | | | |
| | 0/57 | Highland | $O_2$ 99.8 1,200<br>$N_2$ 99.99 150 | 1 | Nippon Rika | O | | | | |

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TABLE OF AIR SEPARATION PLANTS IN JAPAN

| Company, Plant | Date of Install. | Type | Capacity ($m^3/h$) | No. | Manufacturer | Operating Conditions | | | | Purpose |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Operating | Temporarily resting | Resting | Removed | |
| | 6/61 | Highland | $O_2$ 99.8 1,200<br>$N_2$ 99.99 150 | 1 | Nippon Rika | 0 | | | | |
| Osaka | 1/57 | Highland | $O_2$ 99.8 150<br>$N_2$ 99.99 25 | 1 | Nippon Rika | 0 | | | | |
| | 12/59 | Highland | $O_2$ 99.8 1,200<br>$N_2$ 99.99 150 | 1 | Nippon Rika | 0 | | | | |
| | 5/61 | Highland | $O_2$ 99.8 1,200<br>$N_2$ 99.99 150 | 1 | Nippon Rika | 0 | | | | |
| Kokura | 5/57 | Highland | $O_2$ 99.8 500<br>$N_2$ 99.99 50 | 1 | Nippon Rika | 0 | | | | |

TABLE OF AIR SEPARATION PLANTS IN JAPAN

| Comp ny,Plant | Date of Install. | Type | Capacity ($m^3/h$) | No. | Manufac-turer | Operating Conditions | | | | Purpose |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Opera-ting | Tempor-arily resting | Rest-ing | Remov-ed | |
| Nagoya | 9/57 | Highland | $O_2$ 99.8 500<br>$N_2$ 99.99 50 | 1 | Nippon Rika | 0 | | | | |
| | 1/61 | Highland | $O_2$ 99.8 1,200<br>$N_2$ 99.99 150 | 1 | Nippon Rika | 0 | | | | |
| Kure | 6/57 | Highland | $O_2$ 99.8 500<br>$N_2$ 99.99 50 | 1 | Nippon Rika | 0 | | | | |
| | 9/60 | Highland | $O_2$ 99.8 1,200<br>$N_2$ 99.99 150 | 1 | Nippon Rika | 0 | | | | |
| Chiba | 3/61 | Highland | $O_2$ 99.8 1,200<br>$N_2$ 99.99 150 | 1 | Nippon Rika | 0 | | | | |

TABLE OF AIR SEPARATION PLANTS IN JAPAN

| Company, Plant | Date of Install. | Type | Capacity ($m^3/h$) | No. | Manufacturer | Operating Conditions | | | | Purpose |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Operating | Temporarily resting | Resting | Removed | |
| Akita Petroleum Chem., Akita | 1958 | 2,000-TO | $O_2$ 99.4 2,000<br>$N_2$ 99.8 300 | 1 | Hitachi Mfg. | 0 | | | | Chem. |
| | 1959 | 2,000-TO | $O_2$ 99.4 2,000<br>$N_2$ 99.8 300 | 1 | Hitachi Mfg. | 0 | | | | Chem. |
| Tokai Gas, Yokkaiichi | 1955 | High-Med. Press. | $O_2$ 95 700<br>$N_2$ 99.9 2,700 | 1 | Nippon Rika | 0 | | | | Ammonia |
| | 1961 | Total Low Press. | $O_2$ 98 4,400<br>$N_2$ 99.99 6,600 | 1 | Nippon Rika | 0 | | | | Ammonia |
| | | Highland | $O_2$ 80 150<br>$N_2$ 99.9 500 | 1 | Nippon Rika | | | | S-1961 | Ammonia |

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TABLE OF AIR SEPARATION PLANTS IN JAPAN

| ny, Plant | Date of Install. | Type | Capacity ($m^3$/h) | No. | Manufacturer | Operating Conditions | | | | Purpose |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Operating | Temporarily resting | Resting | Removed | |
| | | Linde | $O_2$ 98 150<br>$N_2$ 99.9 750 | 1 | Nippon Rika | | | | S-1961 | Ammonia |
| | | Linde | $O_2$ 80 170<br>$N_2$ 99.9 500 | 1 | Nippon Rika | | | | S-1961 | Ammonia |
| Tohoku Fertilizer | 1948 | Highland | $O_2$ 99.5 50<br>$N_2$ 99.9 450 | 1 | Nippon Rika | | Intermittent 0 | | | Ammonium Sulfate |
| | 1956 | Linder Frankel | $O_2$ 99.5 100<br>$O_2$ 98.0 2,500<br>$N_2$ 99.8 2,000 | 1 | Nippon Rika | 0 | | | | Ammonium Sulfate |
| Kyowa Chem., Ube | 1956 | Linder Frankel | $O_2$ 98 2,200<br>$N_2$ 99.9 2,400 | 1 | Hitachi Mfg. | 0 | | | | Ammonia |

TABLE OF AIR SEPARATION PLANTS IN JAPAN

| Company, Plant | Date of Install. | Type | Capacity ($m^3/h$) | No. | Manufacturer | Operating Conditions | | | | Purpose |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Operating | Temporarily resting | Resting | Removed | |
| | 1956 | Linder Frankel | $O_2$ 98 2,200<br>$N_2$ 99.9 2,400 | 1 | Nippon Rika | 0 | | | | Ammonia |
| Kyowa Gas Chem., Chujo | 1961 | 4,500-TO | $O_2$ 98 4,500<br>$N_2$ 99.99 4,000 | 1 | Hitachi Mfg. | 0 | | | | Chem. |
| Mitsui Petroleum Chem., Otake | 1961 | 1,400-TO | $O_2$ 99 1,400<br>$N_2$ 99.99 2,500 | 1 | Hitachi Mfg. | 0 | | | | Chem. |
| Showa Electric, Kawasaki | 9/30 | Linde | $O_2$ 90<br>$N_2$ 99.9 1,200 | 2 | Linde | | S-1/60 | | | Ammonia |
| | 3/37 | Linde | $O_2$ 92<br>$N_2$ 99.9 1,600 | 3 | Linde | | S-1/60 | | | Ammonia |

TABLE OF AIR SEPARATION PLANTS IN JAPAN

| Company, Plant | Date of Install. | Type | Capacity ($m^3$/h) | No. | Manufacturer | Operating Conditions | | | | Purpose |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Operating | Temporarily resting | Resting | Removed | |
| | 6/47 | Linde | $O_2$ 87<br>$N_2$ 99.9<br>2,000 | 1 | Mitsubishi Kasei | | S-1/60 | | | Ammonia |
| | 1/56 | Claude | Liq. $O_2$ 99.75<br>540ℓ/h<br>$N_2$ 99.99<br>1,800 | 1 | Teikoku Oxygen | 0 | | | | Ammonia |
| Showa Elec., Kawasaki | 2/59 | Total Low Press. | $O_2$ 98.5<br>2,000<br>$N_2$ 99.99<br>5,000 | 1 | Hitachi Mfg. | 0 | | | | Ammonia |
| | 1/60 | Total Low Press. | $O_2$ 98.5<br>3,500<br>$W_2$ 99.99<br>8,500 | 1 | Hitachi Mfg. | 0 | | | | Ammonia |

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TABLE OF AIR SEPARATION PLANTS IN JAPAN

| Company, Plant | Date of Install. | Type | Capacity ($m^3/h$) | No. | Manufacturer | Operating Conditions | | | | Purpose |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Operating | Temporarily resting | Resting | Removed | |
| | 12/62 | Claude | Liq.$O_2$ 99.7 600 $l/h$<br>Liq.$N_2$ 99.99 150 $l/h$<br>Ar 99.99 10 | 1 | Kobe Steel | 0 | | | | Ammonia |
| Toyama | 10/47 | Linde | $O_2$ 50 250<br>$N_2$ 99.9 1,000<br>Pure $O_2$ 99.6 150 | 1 | Mitsubishi Kakoki | 0 | | | | Lime Nitrogen |
| | 3/51 | Linde | $O_2$ 92 200<br>$N_2$ 99.9 1,300<br>Pure $O_2$ 99.7 200 | 1 | Nippon Rika | 0 | | | | Lime Nitrogen |

TABLE OF AIR SEPARATION PLANTS IN JAPAN

| Company, Plant | Date of Install. | Type | Capacity ($m^3$/h) | No. | Manufacturer | Operating Conditions | | | | Purpose |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Operating | Temporarily resting | Resting | Removed | |
| | 4/57 | Linde | $O_2$ 55 250<br>$N_2$ 99.9 1,200<br>Pure $O_2$ 99.6 200 | 1 | Nippon Rika | 0 | | | | Lime Nitrogen |
| Shikase | 1929 | Linde | $O_2$ 96 530<br>$N_2$ 99.9 2,400 | 1 | Linde | 0 | | | | Organic Synthesis |
| | 1929 | Claude | $O_2$ 98 510<br>$N_2$ 99.9 2,400 | 1 | Claude | 0 | | | | Organic Synthesis |
| Kanto Elec., Shibukawa | 1959 | Highland | $O_2$ 30<br>$N_2$ 100 | 1 | Mitsubishi Kakoki | 0 | | | | Inert Gas |
| | 1960 | Highland | $O_2$ 60<br>$N_2$ 200 | 1 | Mitsubishi Kakoki | 0 | | | | Inert Gas |

# TABLE OF AIR SEPARATION PLANTS IN JAPAN

| Company, Plant | Date of Install. | Type | Capacity ($m^3/h$) | No. | Manufacturer | Operating Conditions | | | | Purpose |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Operating | Temporarily resting | Resting | Removed | |
| Toyo Gas, Niigata | 1958 | OF | $O_2$ 98 2,400<br>$N_2$ 99.99 4,000 | 1 | Kobe Steel | 0 | | | | |
| | 1963 | OF | $O_2$ 98 2,350<br>$O_2$ 99.6 200<br>$N_2$ 99.998 4,500 | 1 | Kobe Steel | 0 | | | | |
| Shinetsu Chem., Naoetsu | 9/27 | Claude | $O_2$ 100<br>$N_2$ 600 | 1 | Teikoku Oxygen | | 0 | | | |
| | 9/27 | Claude | $O_2$ 240<br>$N_2$ 1,200 | 1 | Teikoku Oxygen | | 0 | | | |
| | 7/47 | Claude | $C_2$ 75<br>$N_2$ 500 | 1 | Nippon Rika | | 0 | | | |

TABLE OF AIR SEPARATION PLANTS IN JAPAN

| Company, Plant | Date of Install. | Type | Capacity ($m^3/h$) | No. | Manufacturer | Operating Conditions | | | | Purpose |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Operating | Temporarily resting | Resting | Removed | |
| | 5/48 | Linde with Ammonia Recycle | $O_2$ 120<br>$N_2$ 1,100 | 1 | Nippon Rika | | 0 | | | |
| | 6/62 | Total Low Pressure | $O_2$ 7,700<br>$N_2$ 5,000 | 1 | Nippon Rika | 0 | | | | |
| Takeo | 6/29 | Claude | $O_2$ 110<br>$N_2$ 550 | 1 | Teikoku Oxygen | 0 | | | | |
| | 7/47 | Claude | $O_2$ 45<br>$N_2$ 550 | 1 | Teikoku Oxygen | 0 | | | | |
| | 4/50 | Claude | $O_2$ 110<br>$N_2$ 550 | 1 | Teikoku Oxygen | 0 | | | | |
| Nitto Chem., Yatsudo | 1948 | N R | $N_2$ 99.9<br>1,000 | 1 | Kobe Steel | | | 0<br>S-1960 | | Ammonium Sulfate |

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TABLE OF AIR SEPARATION PLANTS IN JAPAN

| Company, Plant | Date of Install. | Type | Capacity ($m^3/h$) | No. | Manufacturer | Operating Conditions | | | | Purpose |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Operating | Temporarily resting | Resting | Removed | |
| | 1952 | Linde | $O_2$ 98.5 200<br>$N_2$ 99.9 1,000 | 1 | Kobe Steel | | | 0<br>S-1960 | | Ammonium Sulfate |
| | 1952 | Linde | $O_2$ 99.5 275<br>$N_2$ 98 1,250 | 1 | Mitsubishi Kakoki | | | 0<br>S-1960 | | Ammonium Sulfate |
| | 1960 | N R - 26 | $O_2$ 99.6 4,000<br>$N_2$ 99.99 4,500 | 1 | Nippon Rika | 0 | | | | Ammonium Sulfate |
| Yokohama | 1952 | Total Low Pressure N R - 26 | $O_2$ 99.6 4,400<br>$N_2$ 99.99 5,000 | 1 | Nippon Rika | 0 | | | | Ammonium Sulfate |
| Nippon Rayon, Uji | 1955 | Linde | $N_2$ 120 | 1 | Kobe Steel | 0 | | | | For Purging |
| | 1957 | Linde | $N_2$ 150 | 1 | Nippon Rika | 0 | | | | For Purging |

TABLE OF AIR SEPARATION PLANTS IN JAPAN

| Company, Plant | Date of Install. | Type | Capacity ($m^3/h$) | | No. | Manufacturer | Operating Conditions | | | | Purpose |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Operating | Temporarily resting | Resting | Removed | |
| | 1959 | Linde | $N_2$ | 150 | 1 | Nippon Rika | 0 | | | | For Purging |
| | 1960 | Linde | $N_2$ | 150 | 1 | Nippon Rika | 0 | | | | For Purging |
| | 1962 | Linde | $N_2$ | 300 | 1 | Nippon Rika | 0 | | | | For Purging |
| | 1962 | Linde | $N_2$ | 1,000 | 1 | Hitachi Mfg. | 0 | | | | For Purging |
| Teiko Jinken, Matsuyama | 1957 | N E | $N_2$ | 250 | 2 | Kobe Steel | | | | S-10/1962 | |
| Teikoku Jinken, Matsuyama | 1959 | Claude | $O_2$ | 100 | 1 | Mitsubishi Kasei | 0 | | | | |
| | | | $N_2$ | 500 | | | | | | | |
| | 1960 | Claude | $O_2$ | 100 | 1 | Mitsubishi Kasei | 0 | | | | |
| | | | $N_2$ | 550 | | | | | | | |
| Mitsubishi Elec., Itami | 1946 | Highland | $O_2$ | 30 | 1 | Mitsubishi Kasei | | | | S-1951 | For Home Use |

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# TABLE OF AIR SEPARATION PLANTS IN JAPAN

| Company, Plant | Date of Install. | Type | Capacity ($m^3/h$) | No. | Manufacturer | Operating Conditions | | | | Purpose |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Operating | Temporarily resting | Resting | Removed | |
| Nippon Kogyo, Hitachi | 1956 | 1,800-T O | $O_2$ 95 1,800<br>$N_2$ 99.5 30 | 1 | Hitachi Mfg. | 0 | | | | Methanol |
| Saganoseki | 1959 | 600-T O | $O_2$ 98 600 | 1 | Hitachi Mfg. | 0 | | | | Methanol |
| Teikoku Oxygen, Amagasaki | 1952 | P A-600 L | $O_2$ 99.6 600 l/h<br>$N_2$ 99.99 500 | 1 | Teikoku Oxygen | | | | S-1963 | For Home Use |
| | 1954 | P A-600 L | $O_2$ 99.6 600 l/h | 1 | Teikoku Oxygen | | 0 | | | For Home Use |
| | 1956 | P A-600 L | $O_2$ 99.6 600 l/h | 1 | Teikoku Oxygen | | 0 | | | For Home Use |
| | 1957 | P A-600 L | $O_2$ 99.6 600 l/h | 1 | Teikoku Oxygen | | 0 | | | For Home Use |
| | 1961 | P A-2,400 L | $O_2$ 99.6 2,400 l/h | 1 | Teikoku Oxygen | 0 | | | | For Home Use |
| Yawata | 1957 | P A-600 L | $O_2$ 99.6 600 l/h | 1 | Teikoku Oxygen | 0 | | | | For Home Use |

TABLE OF AIR SEPARATION PLANTS IN JAPAN

| Company, Plant | Date of Install. | Type | Capacity ($m^3/h$) | No. | Manufacturer | Operating Conditions | | | | Purpose |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Operating | Temporarily resting | Resting | Removed | |
| Chiba | 1960 | P A-600 L | $O_2$ 99.6 600 l/h | 1 | Teikoku Oxygen | 0 | | | | For Home Use |
| | 1958 | P A-600 L | $O_2$ 99.6 600 l/h | 1 | Teikoku Oxygen | 0 | | | | For Home Use |
| | 1959 | P A-600 L | $O_2$ 99.6 600 l/h | 1 | Teikoku Oxygen | 0 | | | | For Home Use |
| | 1962 | P A-2,400 L | $O_2$ 99.6 2,400 l/h | 1 | Teikoku Oxygen | S-4/63 plan | | | | For Home Use |
| Tokyo | 1961 | V A-500 | $O_2$ 99.6 500 | 1 | Teikoku Oxygen | 0 | | | | For Home Use |
| Kanagawa | 1962 | V A-500 | $O_2$ 99.6 500 | 1 | Teikoku Oxygen | 0 | | | | For Home Use |
| Kyodo Oxygen, Wakayama | 10/62 | Hitachi High-Low Pressure Type (T-O-H) | $O_2$ 99.5 6,000 | 1 | Hitachi Mfg. | 0 | | | | Rev. Fur. Opn.Hear. Scarhing (sic) |

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TABLE OF AIR SEPARATION PLANTS IN JAPAN

| Company, Plant | Date of Install. | Type | Capacity ($m^3/h$) | No. | Manufacturer | Operating Conditions | | | | Purpose |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Operating | Temporarily resting | Resting | Removed | |
| | 12/62 | Hitachi High-Low Pressure Type (T-O-H) | $O_2$ 99.5 6,000 | 1 | Hitachi Mfg. | Under construction | | | | Rev.Fur. Opn.Hear. Scarhing (sic) |
| Kokura | 9/60 | Hitachi Closed Circuit Type Liquid Oxygen Method | $O_2$ 99.5 3,780 | 1 | Hitachi | 0 | | | | Rev.Fur. |
| | 9/62 | Hitachi Closed Circuit Type Liquid Oxygen Method | $O_2$ 99.5 4,100 | 1 | | 0 | | | | Rev.Fur. |

## Preview of the Next Edition /46

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World Market, Etc.

## Postscript by the Editor

As indicated in the preface, this survey was headed by Prof. Kitagawa as a part of the accident analysis which is conducted by the Safety Engineering Association. The survey was carried out by organizing a study committee which is composed of the Inorganic Section of the Ministry of International Trade and Industry, and the industrial society.

The survey arranged and analyzed the accidents occurred in this country up to the present, together with those occurring in foreign countries. As it appears to be extremely informative, it is desired that the reports be viewed by many readers for the prevention of accidents. They were simultaneously published by the Safety Engineering Association and the Ammonium Sulfate Association.

A field trip by the editing committee was conducted on June 27 for the first time in several years. The trip was made to the Sagamibara Plant which is the most modern plant of Nippon Metal Industry Company. The plant is

situated in the middle of the Sagami Plain encompassing a large area. Green lawns were planted, and the surroundings were out of this world. Despite of the rain the plant was inspected for approximately 1.5 hours. The plant is nearly completely automated and is operated by a small number of people. It is said that 70% of the products are exported. Since the plant is modern and is designed extremely logically, it is playing a predominant role in the export competition. "It is the exemplification of the victory of the technology innovation," was the undivided opinion shared by the plant manager and the other members of the technical staff.

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